2021-22 CATALOG

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**Fall Semester admission only*

Graduate Programs by Degree
WPI offers graduate study leading to the master of science, master of engineering, master of mathematics for educators, master of business administration, and the doctor of philosophy degrees.

The schedule of courses over a period of time generally allows a student taking three or four courses per semester to complete the course requirements for most Master's degree programs in about two years. Students taking two courses per semester complete the course requirements for the master of science or engineering degrees or the master of business administration degree in about three years.

Doctor of Philosophy (Ph.D.) Degrees*
Available in the following programs:

- Aerospace Engineering
- Applied Physics
- Biochemistry
- Bioinformatics and Computational Biology
- Biology and Biotechnology
- Biomedical Engineering
- Business Administration
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- Civil Engineering
- Computational Media
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- Interdisciplinary Studies
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- Mathematical Sciences
- Mechanical Engineering
- Physics
- Robotics Engineering
- Social Science and Policy Studies
- Statistics
- Systems Engineering

**available only on a full-time basis*

Master of Science (M.S.) Degrees

Available, on a full-time and part-time basis, in the following programs:

- Aerospace Engineering
- Applied Mathematics
- Applied Physics
- Applied Statistics
- Biochemistry*
- Bioinformatics and Computational Biology
- Biology/Biotechnology
- Biomedical Engineering
- Biotechnology
- Business Analytics
- Chemical Engineering*
- Chemistry*
- Civil Engineering
- Computer Science
    - Specializing in Computer Security
- Construction Project Management
- Data Science
- Electrical and Computer Engineering
- Environmental Engineering
- Financial Mathematics
- Fire Protection Engineering
- Industrial Mathematics
- Information Technology
- Innovation with User Experience
- Interactive Media & Game Development
- Interdisciplinary Studies
    - Power Systems Management
    - Systems Modeling
- Learning Sciences and Technologies
- Management
- Manufacturing Engineering
- Materials Process Engineering
- Materials Science and Engineering
- Mechanical Engineering
- Neuroscience
- Operations and Supply Chain Analytics
- Physics
- Robotics Engineering
- System Dynamics
- System Dynamics and Innovation Management
- Systems Engineering
- Systems Engineering Leadership

**available only on a full-time basis*

Master of Engineering (M.E.) Degrees

Available in the following programs:

- Biomedical Engineering
- Civil Engineering
    - Environmental Engineering
    - Master Builder Program
- Electrical and Computer Engineering
- Power Systems Engineering
- Master of Business Administration (M.B.A.) Degree

Building on WPI's strengths as a technological university, the WPI MBA provides STEM professionals with the business skills to drive change and lead innovation within technology-based organizations. The degree requirements are described in this catalog and in a separate brochure available from the Foisie Business School at 508-831-4665, or at business.wpi.edu.

Master of Mathematics for Educators (MME) Degree

WPI offers a Master in Mathematics for Educators, a part-time program for teachers of mathematics at the middle school, secondary, and community college levels. Students in this program may earn a content-based degree afternoons and evenings while still teaching full time. Taught by professors of mathematics at WPI, the program is designed to permit the teachers to learn from professors' research interests and includes an understanding of current developments in the field. Scholarship aid, which covers approximately 40% of the cost of tuition, is available to qualified participants. The MME degree may be used to satisfy the Massachusetts Professional License requirements, provided the person holds an Initial License.

Master of Science in Mathematics for Educators (MMED) Program

Designed especially for middle school, high school and community college educators, the Master of Science in Mathematics for Educators is a part-time, afternoon and evening program of study that puts emphasis on math content courses while also incorporating core assessment and evaluation theory coursework and a culminating project designed by the participant. Participants are additionally able to keep up-to-date on the latest research by working with professors in the field. The MMED may satisfy Massachusetts requirements to move from an Initial License to a Professional License.

Master of Science in Physics for Educators (MPED) Program

Designed especially for middle school, high school and community college educators, the Master of Science in Physics for Educators is a part-time, afternoon and evening program of study that puts emphasis on physics content courses while also incorporating core assessment and evaluation theory coursework and a culminating project designed by the participant. Participants are additionally able to keep up-to-date on the latest research by working with professors in the field. The MPED may satisfy Massachusetts requirements to move from an Initial License to a Professional License.

Combined Bachelor/Master's Program

Introduction

WPI undergraduates can begin work on a graduate degree by enrolling in a combined Bachelor's/Master's program. This accelerated course of study allows students to obtain an M.S. degree after only five years of full-time work (i.e., typically one year after completion of the B.S.). Students often obtain the B.S. and M.S. in the same field or department, but with careful planning some students complete the combined B.S./M.S. program in two different fields. Students are encouraged to review the various options available for pursuing the combined B.S./M.S. program within a specific department or program by visiting the relevant section within the Graduate Catalog. (Throughout this section, "M.S." will be used to refer to all Master's-level degrees; most students who complete the combined program obtain the M.S.).

Planning Your Program

Because B.S./M.S. students use some approved courses to satisfy the requirements of both degrees simultaneously, it is crucial for them to plan their curriculum early in their undergraduate career.

The specific course and MQP requirements for a B.S./M.S. program are determined individually, so students should consult with their own advisor as well as the graduate coordinator in the department in which they plan to pursue their M.S. degree early in their Junior year. This consultation, or series of consultations, should produce a slate of approved undergraduate courses that will be used for graduate credit. Sometimes the instructors of these courses will ask B.S./M.S. students to complete additional work, or will otherwise hold them to higher standards of achievement. Note: no undergraduate credit may be counted toward a graduate business degree.

A student's advisor and graduate coordinator will also determine what role the MQP will play in the B.S./M.S. program. Sometimes the MQP provides a foundation for a thesis. In cases where the B.S. and M.S. are not awarded in the same field, the MQP usually relates to the graduate program's discipline.

Once the specific course and MQP requirements have been established, students complete a Course Selection Form which is submitted to the relevant department(s) for approval. This written agreement constitutes the set of conditions that must be met for a student to complete the B.S./M.S. program. They are a plan for completing the requirements for both degrees and they will not supersede or otherwise obviate departmental and university-wide requirements for either degree. The completed, signed form must be submitted to the Registrar before the student may matriculate in the combined program.

How to Apply

Students almost always apply for admission to the B.S./M.S. program in their Junior year, typically after they have established their curriculum and other program requirements and completed the Course Selection Form with their faculty advisors. Applications are submitted to the Office of Graduate Admissions and are processed with all other graduate applications. Once a decision has been reached, the Office of Graduate Admissions will notify the student, usually within six weeks of receiving the application.

Program Requirements

Only registered WPI undergraduates may apply for admission to the combined B.S./M.S. programs. Students are considered undergraduates, no matter what courses they have completed, until they have met all of the requirements for the Bachelor's degree. In order to receive the B.S. and the M.S., all of the requirements for both degrees must be completed.

In most departments a student may take up to four years of uninterrupted study to complete the Master's portion of the B.S./M.S. program. There are exceptions, however, so students are advised to discuss their timetable with the appropriate advisor or graduate coordinator. Students who stop registering for classes for an extended length of time may be asked to petition the Committee for Graduate Studies and Research (CGSR) to continue their program.

Credit Equivalence and Distribution

No more than 40% of the credit hours required for the Master's degree, and which otherwise meet the requirements for each degree, may be used to satisfy the requirements for both degrees. In some departments, students may not double-count more than 30% of their graduate credits. Consult the department entries in the graduate catalog for the requirements of your program.

Double-counted courses are recorded on the transcript using the credit hours/units and grades appropriate at the graduate or undergraduate levels. For students in the combined B.S./M.S. program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 2 graduate credit hours, while graduate courses applied toward the undergraduate degree are awarded undergraduate units with a conversion rate of 1 graduate credit hour = 1/6 undergraduate unit.

Interdisciplinary Master's and Doctoral Programs

WPI encourages interdisciplinary research. Students interested in such options should do so with the assistance of WPI faculty, as these programs require internal sponsorship

Graduate and Advanced Graduate Certificates

Keeping pace with technological advancement today is a never-ending task. WPI's innovative graduate certificate programs help technical and business professionals keep up to date with advances in technologies and business practices without a commitment to a graduate degree program. WPI offers two certificate programs: the Graduate Certificate (GC) and the Advanced Certificate (AC).

Graduate Certificate Program

The Graduate Certificate (GC) provides opportunities for students holding undergraduate degrees to continue their study in an advanced area. A bachelor's degree is the general prerequisite; however, some departments also look for related background when making admission decisions. GC students are required to complete four to six courses totaling 12 to 18 credit hours in their area of interest. GC courses can be applied to a WPI graduate degree if the student is subsequently admitted to a degree program in the same discipline.

Additional programs may be developed in consultation with an academic adviser.
For the most current listings go to https://www.wpi.edu/academics/study

Advanced Certificate Program

The Advanced Certificate (AC) provides master's degree holders with an opportunity to continue their studies in advanced topics in the discipline in which they hold their graduate degrees or that is closely related to their graduate fields. The AC includes four to six courses totaling 12 to 18 credits, none of which were included in the student's prior master's program or in any other certificate program.

Each participating department identifies one or more guideline programs; however, each student's program of study may be customized with the academic advisor's approval to satisfy the student's unique interests.

Additional specializations may be developed in consultation with an academic advisor.

Application Process

Application to the GC and AC requires submission of an official application form, official transcripts of all college-level work, and a $70 application fee (waived for WPI alumni) to the Office of Graduate Admissions. Individual departments may require additional information. International students may apply to certificate programs. However, for WPI to issue the I-20 form for a student visa, international students must be registered for a minimum of nine credits on campus during their first semester and must complete their program within one year. Students apply online at http://grad.wpi.edu/+apply.

Admission and Matriculation

Admission to a certificate program is granted by the faculty of the sponsoring department through the Graduate Admissions Office. A student accepted into a master's or doctoral program may apply to a certificate program only after the graduate committee of the degree (M.S. or Ph.D.) granting program or department approves, and as long as all of the following conditions are met:

1. Admitted master's or doctoral program students may be awarded one certificate for which course credits

are used to satisfy requirements for both the graduate degree (M.S. or Ph.D.) and the Graduate Certificate or advanced graduate certificate.
2. Graduate course credits used to satisfy the graduate certificate or advanced graduate certificate and graduate degree (M.S. or Ph.D.) requirements cannot also be counted toward a third credential, such as a Graduate Certificate, Advanced Graduate Certificate, graduate or undergraduate degree.
3. No more than one-third of course credit applied to a Graduate Certificate or advanced Graduate Certificate or graduate degree can be earned by transfer credit.

A Graduate or Advanced Certificate will not be awarded without admission into a certificate program.

Registration Procedures

GC and AC students register at the same time as other WPI graduate students, follow the same registration procedures, and participate in the same classes.

Tuition and Fees

Tuition and fees for GC and AC students are the same as for all other WPI graduate students.

Plan of Study

Following admission, certificate students will be assigned an academic advisor. Within the first three months of admission, certificate students are required to obtain approval for their Plan of Study from their faculty advisor. The student, the academic advisor and the department will maintain copies of the Plan of Study. Students may initiate written requests to the advisor to modify the program. The student, the academic advisor and the department must retain copies of any approved program modification(s).

Academic Policies

Academic policies regarding acceptable grade point averages for certificate students follow the same guidelines as those established for degree-seeking graduate students with the following exception: If a GC or AC student's grade point average falls below 2.5 after completing nine credits, he/she will be withdrawn from the program unless the academic department intervenes.

Program Completion

Satisfactory completion of a GC or AC requires a cumulative grade point average of 3.00 or better (A = 4.0) with individual course grades of C or better. Upon satisfactory completion of the program, students will receive a certificate of Graduate Study or a Certificate of Advanced Graduate Study in the chosen discipline. Students are responsible for submitting the signed, completed Plan of Study to the Registrar's Office to receive the certificate.

Transferring from a Certificate Program to a Graduate
Degree Program

Admission to a certificate program is not equivalent to admission to a degree program. However, many certificate students eventually choose to pursue a WPI degree program. Students enrolled in a certificate program who would like to pursue a master's or doctorate must meet the application and admission requirements for the specific degree program as described in the Graduate Catalog. All GC and AC course credits will apply to a WPI graduate degree provided that the student is admitted to a graduate degree program and the courses are acceptable to that degree program.

Earning a Second Certificate

A student admitted into a certificate program who wishes to work toward a second certificate program must apply to that second certificate program for admission. The application fee will be waived for the second application. Courses counted toward one certificate may not count toward any other certificate.

WPI Online

WPI Online programs are designed with the working professional in mind. No matter your location or schedule, an advanced degree from WPI is within reach.

For more than forty years, we have delivered superior distance education to graduate students around the world. It is our mission to make sure each student feels connected, supported, and successful. Each student will be assigned to a Student Success Manager who will support your educational journey, help you overcome obstacles, and answer any questions you might have.

Our online students receive the same world-class instruction as our on-campus students, delivered by expert WPI faculty. Support services tailored to the needs of working professionals are also available, in addition to the resources offered to every WPI student.

Quality Graduate Education

Our convenient online courses are open to both on-campus and distance learners.

All courses and degrees delivered online contain the same content and material one would receive in a traditional classroom, and students earn the same certificates and degrees as their on-campus counterparts. In addition, online students have the benefit of 24/7 access to their courses.

Please note: online students are held to the same high standard as all WPI students. They are expected to keep pace with course content and engage actively in all of their courses, adding value to the collaborative learning environment.

This level of participation requires regular access to high-speed Internet via a personal computer.

Programs of Study

WPI offers online graduate programs in a wide array of topics, with new programs added throughout the academic year.

Please visit online.wpi.edu for the most current online offerings.

Student Services

Online students have unique questions, concerns, and needs. With WPI Online, you're never alone. You will benefit from the services our on-campus students receive, and then some, including:

- Online orientation
- Virtual library access
- Software & mobile support
- Career counseling & placement
- Tuition & financial aid help

Plus, a dedicated team provides our online students with individualized support every step of the way, from application to graduation.

Contact and Information:

WPI Online provides online graduate students with personalized assistance and acts as their liaison to all other university offices. Students can reach WPI Online via the website, by phone, and by email:

WPI Online

online@wpi.edu

+1-508-831-5517

www.wpi.edu/+online

Worcester Polytechnic Institute (WPI) participates in the National Council State Authorization Reciprocity Agreement (NC-SARA).

NC-SARA:

- Pertains to approval of distance education courses and programs offered across state lines by postsecondary institutions that already have degree authorization in at least one state.
- Centralizes the authorization process.
- Is intended to be consistent with federal law and there is subject to change based on federal rulemaking.

NC-SARA also provides additional resources for students who are unable to resolve complaints through the university. Additional information can be found at https://www.wpi.edu/academics/online/support/state-authorization.

Admission Information

Applying to WPI

Prospective graduate students submit their applications for all WPI graduate programs online at www.grad.wpi.edu/+apply.

Each department requires different credentials for admission. A table of each department's requirements can be found on page 11.

A completed undergraduate degree is a pre-requisite for beginning all graduate degree programs at WPI. All graduate students are expected to have completed their undergraduate degree at the time of matriculation.

WPI admission requirements include the following:

- A completed Application for Admission to Graduate Study.
- A non-refundable $70 application fee (waived for WPI alumni and matriculating WPI students).
- College transcripts in English and the original language from all accredited degree-granting institutions attended. Admitted students must provide official transcripts with an indication that the bachelor's degree has been awarded before they matriculate.
- Three letters of recommendation from individuals who can comment on the applicant's qualifications for pursuing graduate study in the chosen field. Applicants are required to invite their recommenders to submit letters through the online application only.

- Several programs require a statement of purpose. This is a brief essay discussing background, interests, academic intent, and the reasons the applicant feels s/he would benefit from the program. The statement of purpose must be submitted electronically with the online application.
- The School of Business requires all applicants to submit a resume and video essay electronically with the online application.
- Proof of English language proficiency must be submitted by all applicants for whom English is not their first language. Applicants must submit an official score report from either the TOEFL (Test of English as a Foreign Language) or IELTS (International English Language Testing Service). WPI does not accept paper copies of these scores; only official scores sent electronically from the testing service will be accepted. The minimum scores for admission are: TOEFL: 84 (internet-based test)

IELTS: 7.0 overall band score with no
sub-score lower than 6.5

These are the minimum scores for admission to WPI. Some departments have higher minimums. Students being considered for a Teaching Assistant position will have a higher required minimum TOEFL. Please see the section on Financial Information/Teaching Assistantships for more details.

Applicants who have completed two years of full-time study at a college or university in the U.S., the U.K., Ireland, Australia, New Zealand, or the Anglophone regions of Africa, Canada, or the Caribbean, within five years of matriculating at WPI are not required to submit TOEFL or IELTS scores.

WPI's institutional code for the TOEFL is 3969. Scores are valid for two years from the test date. For more information, or to take the TOEFL, go to: www.toefl.org. For more information on the IELTS, or to take the exam, go to: www.ielts.org.

Some programs require the GRE (Graduate Record Examination). Consult the table on page 11 for program requirements. There is no WPI minimum GRE or GMAT score for admission. WPI's institutional code for the GRE and GMAT is 3969. Scores are valid for five years from the test date. For more information, or to take the GRE go to: www.ets.org/gre or www.gmat.com.

The Office of Graduate Admissions will retain incomplete applications and their associated credentials for one year after the application was started. If the application remains incomplete for one year, WPI reserves the right to cancel it and destroy all associated documents and credentials.

All applications, letters of recommendation, and all support material become the property of WPI once they have been received by the Office of Graduate Admissions.

Three-Year Bologna-Process Degrees

WPI welcomes applications from students who have three-year Bologna-compliant undergraduate degrees from European universities. Applicants who hold these credentials will be evaluated for admission on a case-by-case basis.

Priority Dates

Students who want to apply for fall admission should submit their applications by the preceding January 1st and complete the dossier as soon as possible after that date.

Students who are seeking admission to the spring semester should submit their applications by the preceding October 1st and complete the dossier as soon as possible after that date.

Some departments have strict deadlines; others admit students year-round. Consult the WPI website for more details.

Funding is disbursed by the admissions committees in each of the academic departments. These decisions are made in tandem with the admissions decision, so there is no separate application for assistantships or fellowships.

Prospective students must indicate that they want to be considered for funding when they apply for admission. The application should be complete on or before January 1st to ensure consideration. Applications that are completed during the two weeks following January 1st will also receive the earliest consideration for funding.

With each passing month the availability of funds decreases, so applications should be completed, if possible, before the end of January.

Admission

Each department, program, or sponsoring group is responsible for making admissions decisions. Their decisions are communicated by the Office of Graduate Admissions. In general, offers of admission are good for one year.

Sometimes a department will recommend admission to a degree program that differs from the program specified in the student's application. Most typically, a department will admit a Ph.D. applicant to a Master's program. Students in such a position should contact the graduate coordinator in their program to find out what criteria they will have to meet to gain admission to the Ph.D. program in the future.

A current WPI graduate student who would like to complete a second graduate degree in another department must apply for admission to the second program. In general, standard application procedures are followed, but a copy of the first application and its supporting materials can sometimes be used as the basis for the second. No application fee is required. Students who wish to change from one degree program to another must complete a second graduate application.

Under some circumstances a student not yet admitted to a program may earn graduate credit towards the requirements for a graduate degree. But such students must keep in mind that permission to register does not constitute admission to a degree or certificate program, nor does it guarantee admission. It is also important to bear in mind that the number credits that can be applied to the degree is limited. Students are thus encouraged to apply for admission to a program at the earliest possible date.

Applicants who would like to be considered for more than one degree program must complete and submit a separate application form for each program.

Confirmation of Admission

Admission to a WPI graduate program is officially granted via a letter from the Office of Graduate Admissions. No other communication from the university (e.g., email from a department) confers admission on an applicant.

The official admission letter asks students to respond to their offer online on the Graduate Admission Response Form. Communication with the department or program directly does not officially confirm the intention to attend, and may not initiate the necessary steps for enrollment.

A non-refundable deposit of $500, which will be credited to tuition and fees, is required of students in the graduate science and engineering programs who plan to attend.

A non-refundable deposit of $1,500, which will be credited to tuition and fees, is required of students in the business school programs who plan to attend.

Deferred Enrollment

An admitted student who wishes to defer enrollment must make a request in writing to the Office of Graduate Admissions. Students typically receive a one-time deferral of up to twelve months. Funded students generally can not defer their funding. WPI requires a $500 non-refundable deposit for all graduate science, global school and engineering student deferrals. A $1,500 non-refundable deposit is required for all business school student deferrals. This deposit will be credited to the student's tuition upon arrival.

Admissions Terms and Conditions

Please note that WPI's offer of admission and your subsequent matriculation at WPI is contingent upon the following terms and conditions. Matriculation for the purposes of these terms and conditions is defined as the earlier of a student's arrival on campus or WPI's first day of classes for the term/semester. WPI reserves the right to revoke your offer of admission any time prior to your matriculation at WPI if:

- You do not graduate or do not receive a diploma at the end of the academic year.
- You have misrepresented any part of your admissions application, including but not limited to any behavioral or disciplinary issues and academic dishonesty.
- You experience a drop in grade performance during the remainder of the academic year.
- Information that comes to the attention of WPI that is deemed unacceptable by WPI.

Application Requirements

Graduate Certificates

Applicants to all graduate certificate programs must submit the following credentials for the application to be complete.

1. Online application form
2. Transcripts from all colleges or universities attended, and official proof of a completed Bachelor's degree before matriculating.
3. Proof of English proficiency (for non-native English speakers)
4. $70 application fee

   Individual departments may require additional information.

Master's and Doctoral Degrees

Applicants to all graduate degree programs must submit the following credentials for the application to be complete.

1. Online application form
2. Transcripts from all colleges or universities attended, and official proof of a completed Bachelor's degree before matriculating.
3. Three letters of recommendation, submitted online
4. Proof of English proficiency (for non-native English speakers)
5. Exams and essays as noted online: https://www.wpi.edu/admissions/graduate/how-to-apply
6. $70 application fee

Financial Assistance

Financial assistance from WPI to support graduate students is available in the form of teaching assistantships, research assistantships, other graduate assistantships, fellowships, and internships, and loans. When graduate students are awarded teaching or research assistantships or fellowships that are processed through WPI, the student will receive official notification pertaining to the type and level of financial assistance from the Graduate Studies Office.

Fellowships are defined as full financial support for 12 months. They include a stipend and full tuition of at least 9 credits per semester during the academic year. In summer, there is typically no tuition offered but the fellowship recipient maintains the same stipend. Fellowships carry the specific expectations as defined in the notice of award, and are used to support the student to focus on research in their area of study.

Teaching Assistants are almost always for a full academic year of 9 months (fall and spring, or for students who begin in January, they would be for spring and at least the following fall), and include both a stipend that meets the minimum level, and full tuition of at least 9 credits per semester. The expected responsibilities of Teaching Assistants are to support courses as defined by the supporting department or program. Exceptions are made under special circumstances and must be approved by the Dean of Graduate Studies. Some approved exceptions would include: 1) the student is graduating midway through the year, 2) the support is split between RA and TA for different semesters.

Research Assistants are typically for 9 or 12 months, and must include a stipend that meets the minimum levels required for that type of student, and full tuition of at least 9 credits per semester. The expected responsibilities of Research Assistants are to support research activities as defined by the supporting faculty member.

It is possible to combine multiple sources of support. For example, a student may be a Teaching Assistant for the 9 month academic year and a Research Assistant for the 3 summer months.

For TAs and RAs that have already completed the number of credits required for their pending graduate degree, they may be offered less than 9 credits of tuition, as long as the amount is commensurate with their maintaining full-time student status.

Graduate Assistants are students that are not otherwise supported as full-time Research or Teaching Assistants or Fellows. There is no implied long-term commitment. These students typically receive hourly or fixed stipends and/or partial tuition support for a specific activity defined by a sponsor. The expected responsibilities of Graduate Assistants are typically to support research activities as defined by the sponsor. This classification is intended to provide a means for providing support to graduate students who would otherwise not receive assistantships, typically self-funded Master's students.

Student Loans

Information on financial assistance in the form of loans is available through the WPI Office of Student Aid & Financial Literacy. Students who are U.S. citizens, U.S. nationals, U.S. permanent residents, or fit into other eligible noncitizen categories set forth by the U.S. Department of Education may be eligible for federal Direct Loans, namely the Unsubsidized Loan and/or the Graduate PLUS Loan. To qualify, students must be admitted unconditionally into a graduate degree-granting program, must be enrolled on an at least a half-time basis, defined as at least four credits in a given semester, file a FAFSA, meet all other federal student aid requirements, and must be making satisfactory academic progress. Satisfactory academic progress for Direct Loan borrowing is evaluated on an annual basis at the end of the spring semester. Conditionally admitted students are not eligible for federal Direct Loans.

Private student loans are also available to students enrolled in graduate programs, certificate programs or to students who are not enrolled on an at least half-time basis. A non-citizen or international student may qualify for private loans with a creditworthy U.S. citizen or U.S. permanent resident as a cosigner.

For more information on loan programs, contact the WPI Office of Student Aid & Financial Literacy at +1-508-831-5469, and review https://www.wpi.edu/admissions/tuition-aid/applying-for-aid/graduate-students

Work Expectations for Funded Graduate Students

Teaching Assistantship (TA): A TA position is a full-time, 40 hour commitment. TAs are expected to work up to 20 hours per week on teaching assistant related responsibilities, with the remaining 20 hours to be spent on coursework, professional development, and research responsibilities.

Research Assistantship (RA): A RA position is a full-time, 40 hour commitment. RAs are expected to work at least 20 hours per week on research related responsibilities, with the remaining 20 hours to be spent on coursework and professional development and any remaining balance of time to be spent on research responsibilities.

Fellowships and Training Grants: Graduate students funded through external fellowships should follow the policies stipulated by their funding agency on working hour expectations. If no such policies are in place, the Fellow should follow the guidance for RAs. Graduate Students funded through internal fellowships or training grants should follow the guidance for RAs.

Graduate students that feel they are being routinely asked to exceed these work expectations should first discuss their situation with their research advisor or TA course instructor. If an amenable solution is not reached, the student should discuss their situation with their Graduate Coordinator and/or Department Head or Program Director. If the situation is still not resolved, students should reach out to Graduate Studies.

Grading System and Academic Standards

Grading System

In order to assess progress throughout the graduate program, grades are assigned to the student's performance in course, project and thesis work, except in doctoral dissertation, which will be judged as ACCEPTED or REJECTED. Academic achievement in all other work is based on the following grading system:

A Excellent
B Good
C Pass
D Unacceptable for graduate credit
F Fail
AU Audit
NC No credit (not included in GPA)
P Pass; (not included in GPA)
I Incomplete; transition grade only; becomes grade of F if not changed by instructor within 12 months
W Withdrawal
SP Satisfactory progress; continuing registration in thesis/dissertation/directed research
CR Credit for work at another institution
UP Unsatisfactory progress; this grade remains on the file transcript
AT Attended

Academic Standards

To be considered in good academic standing, graduate students must maintain a cumulative overall GPA of 3.0. Cumulative overall GPA includes all work taken since matriculation, and any coursework taken before matriculation as a graduate student, provided it has not already been counted towards another degree (exception: courses used for another WPI degree that are specifically authorized by the appropriate graduate committee to be double-counted will be included in the new degree's GPA once processed by the Registrar). Transfer credit approved from other schools is not counted in the GPA. Students are reviewed at the conclusion of each semester they are enrolled. Students who fall below the minimum standard of 3.0 cumulative overall GPA will be placed in Academic Warning.

If a student earns a grade lower than C in three or more courses, or if the cumulative overall GPA falls at or below 2.5 after attempting a minimum of 8 credits, the student is academically dismissed.

Academic Warning: Students have one semester of course work to raise their cumulative overall GPA. Students who do not improve their GPA upon the next review will move down to the next level of standing. Students who do not have a cumulative overall GPA of at least 3.0 will remain in Academic Warning.

Academic Probation: Students have one semester of course work to raise their cumulative overall GPA. Students who improve their GPA but still remain below 3.0 will be moved up to Academic Warning. Students who do not improve their GPA upon the next review will move down to the next level of standing.

Academic Dismissal: Students are academically withdrawn from the University. Students may appeal dismissal by submitting a petition to the University Registrar.

Academic standing appeal procedure: Student petitions will be reviewed by the Committee on Graduate Studies and Research. A representative from the student's home department will be present during the appeal process. This petition must be submitted with any supporting documentation no later than the date specified in the dismissal letter, typically two weeks after semester end.

Failure to complete degree milestones as specified by department/program: If a student is in otherwise good standing but fails to meet specified degree milestones, they may be dismissed from the program by the department graduate committee (see individual programs for specifics). Should this happen, the Dean of Graduate Studies and the Registrar will be notified, and the student will be academically dismissed from WPI. The student may formally apply to another degree program, but they may not attend WPI unless they matriculate to another degree program. At the department's discretion, the student may be allowed to take a lesser credential (e.g. a PhD student may be allowed to take a master's degree, or a master's student may be allowed to take a graduate certificate) if not already conferred. In this case, if necessary, the student will be allowed to complete that credential before leaving WPI. There is no appeal process through the Committee on Graduate Studies and Research for students dismissed for failure to complete degree milestones.

A student is expected to expend at least 56 hours of total effort (including classroom time) for each graduate credit. This means that a student in a 3-graduate credit 14-week course is expected to expend at least 12 hours of total effort per week. A student in a 2-graduate credit 7-week course is expected to expend at least 16 hours of total effort per week.

Grade Point Average (GPA)

Grades are assigned the following grade points:

A = 4.0, B = 3.0, C = 2.0, D = 1.0 and F = 0.0. The grade point average is calculated as the sum of the products of the grade points and credit hours for each registered activity (including courses, independent studies, directed research, thesis research and dissertation research) in the average, divided by the total number of credit hours for all registered activities in the average. If a student takes the same course more than once, the course enters the GPA only once, the best grade received for the course being used in the average.

A student's overall GPA is calculated on the basis of all registered activities taken while enrolled as a graduate student at WPI. WPI graduate courses taken before a student had status as a degree-seeking graduate student are included in the over-all GPA. A student's program GPA is calculated on the basis of those WPI courses listed by the student on the student's Application for Graduation form. The transcript will report the overall GPA.

Courses transferred from elsewhere for graduate credit (for which a grade of CR is recorded on the WPI transcript), and courses taken to satisfy undergraduate degree requirements or to remove deficiencies in undergraduate preparation, are not included in either GPA. Registered activities in which the student receives grades of AU, NC, P, I, W, SP or UP are not included in either GPA.

Only registered activities in which a grade of A, B, C, CR, or P was obtained may be used to satisfy courses or credit requirements for a graduate degree.

Grade Appeal and Grade Change Policy

The Student Grade Appeal Procedure affirms the general principle that grades should be considered final. The principle that grades for courses, thesis credit and dissertation credit should be considered final does not excuse an instructor from the responsibility to explain his or her grading standards to students, and to assign grades in a fair and appropriate manner. The appeal procedure also provides an instructor with the opportunity to change a grade for a course or project on his or her own initiative. The appeal procedure recognizes that errors can be made, and that an instructor who decides it would be unfair to allow a final grade to stand due to error, prejudice or arbitrariness may request a change of grade for a course or project without the formation of an ad hoc committee. An instructor may request a grade change by submitting a course, thesis credit or dissertation credit grade change request in writing to the Registrar at any time prior to a student's graduation.

The purpose of the Grade Appeal Policy is to provide the student with a safeguard against receiving an unfair final grade, while respecting the academic responsibility of the instructor. Thus, this procedure recognizes that:

- Every student has a right to receive a grade assigned upon a fair and unprejudiced evaluation based on a method that is neither arbitrary nor capricious; and,
- Instructors have the right to assign a grade based on any method that is professionally acceptable, submitted in writing to all students, and applied equally.

Instructors have the responsibility to provide careful evaluation and timely assignment of appropriate grades. Course and project grading methods should be explained to students at the beginning of the semester. WPI presumes that the judgement of the instructor of record is authoritative and the final grades assigned are correct.

A grade appeal shall be confined to charges of unfair action toward an individual student and may not involve a challenge of an instructor's grading standard. A student has a right to expect thoughtful and clearly defined approaches to course and research project grading, but it must be recognized that varied standards and individual approaches to grading are valid. The grade appeal considers whether a grade was determined in a fair and appropriate manner; it does not attempt to grade or re-grade individual assignments or projects. It is incumbent on the student to substantiate the claim that his or her final grade represents unfair treatment, compared to the standard applied to other students. Only the final grade in a course or project may be appealed. In the absence of compelling reasons, such as clerical error, prejudice, or capriciousness, the grade assigned by the instructor of record is to be considered final.

Only arbitrariness, prejudice, and/or error will be considered as legitimate grounds for a grade change appeal.

Arbitrariness: The grade awarded represents such a substantial departure from accepted academic norms as to demonstrate that the instructor did not actually exercise professional judgment.

Prejudice: The grade awarded was motivated by ill will and is not indicative of the student's academic performance.

Error: The instructor made a mistake in fact.

This grade appeal procedure applies only when a student initiates a grade appeal and not when the instructor decides to change a grade on his or her own initiative. This procedure does not cover instances where students have been assigned grades based on academic dishonesty or academic misconduct. Academic dishonesty or misconduct are addressed in WPI's Academic Honesty Policy. Also excluded from this procedure are grade appeals alleging discrimination, harassment or retaliation in violation of WPI's Sexual Harassment Policy, which shall be referred to the appropriate office at WPI as required by law and by WPI policy.

The Grade Appeal Procedure strives to resolve a disagreement between student and instructor concerning the assignment of a grade in a collegial manner. The intent is to provide a mechanism for the informal discussion of differences of opinion and for the formal adjudication by faculty only when necessary. In all instances, students who believe that an appropriate grade has not been assigned must first seek to resolve the matter informally with the instructor of record. If the matter cannot be resolved informally, the student must present his or her case in a timely fashion in the procedure outlined below. Under normal circumstances, the grade appeal process must be started near the beginning of the next regular academic semester after the disputed grade is received.

Student Grade Appeal Procedure

1. A student who wishes to question a grade must first discuss the matter with the instructor of record within one week after the start of the next regular academic semester (fall or spring) or term (A, B, C or D) after receiving the grade. Late appeals will only be reviewed at the discretion of the Faculty Review Committee (FRC). In most cases, the discussion between the student and the instructor should suffice and the matter will not need to be carried further. The student should be aware that the only valid basis for grade appeal beyond this first step is to establish that an instructor assigned a grade that was arbitrary, prejudiced or in error.
2. If the student's concerns remain unresolved after the discussion with the instructor, the student may submit a written request to meet with the appropriate Department Head or Program Coordinator within one week of speaking with the instructor. The appropriate Department Head or Program Coordinator will meet with the student within one week and, if he or she believes that the complaint may have merit, with the instructor. After consultation with the appropriate Department Head or Program Coordinator, the instructor may choose to change the grade in question or leave the grade unchanged. The Department Head or Program Coordinator will communicate the result of these discussions to the student.
3. If the matter remains unresolved after the second step, the student should submit a written request within one week to the Provost's Office to request an ad hoc committee for Appeal of a Grade. The Provost's representative (the Dean of Graduate Studies, or alternate) will meet with the student and will ask the Faculty Review Committee (FRC) to appoint the ad hoc committee for Appeal of a Grade. The Chair of the FRC will select the members of the ad hoc committee and serve as its non-voting chair. The ad hoc committee for appeal of a course, thesis credit or dissertation credit grade will be composed of three faculty members. The first member will be the Department Chair, Program Coordinator or Departmental Graduate Coordinator from the instructor's Department. If all three have a conflict of interest, the Provost's representative will serve on the ad hoc committee. The remaining two members will be two FRC members with no conflicts of interest with either the student or the instructor. Apparent conflicts of interest would include the student's thesis

or dissertation advisor, members of the student's graduate committee, and faculty members with close research collaboration or project advising relationships with the instructor. The Chair of the FRC requests a written statement from the student and a written response from the instructor. The ad hoc committee examines the written information and may gather additional information as it sees fit.
4. Through its inquiries and deliberations, the ad hoc committee is charged to determine whether the grade was assigned in a fair and appropriate manner or whether clear and convincing evidence of arbitrariness, prejudice, and/or error might justify changing the grade. The ad hoc committee will make its decisions by a majority vote.
5. If the ad hoc committee concludes that the grade was assigned in a fair and appropriate manner, the ad hoc committee will report its conclusion in writing to the student and the instructor. The decision of the ad hoc committee is final and not subject to appeal.
6. If the ad hoc committee determines that compelling reasons exist for changing the grade, it would request that the instructor make the change, providing the instructor with a written explanation of its reasons. At this point, the instructor may change the grade. If the instructor declines to change the grade, he or she must provide a written explanation for refusing. If the ad hoc committee concludes that the instructor's written explanation justifies the original grade, the ad hoc committee will report this in writing to the student and instructor and the matter will be closed. If the ad hoc committee concludes that it would be unjust to allow the original grade to stand, the ad hoc committee will then determine what grade is to be assigned. The new grade may be higher than, the same as, or lower than the original grade. Having made this determination, the three members of the committee will sign the grade change form and transmit it to the Registrar. The instructor and student will be advised of the new grade. Under no circumstances may persons other than the original faculty member or the ad hoc committee change a grade. The written records of these proceedings will be filed in the student's file in the Registrar's Office.

Project, Thesis, and Dissertation Advising

A graduate project, thesis, and/or dissertation must include a faculty advisor-of-record at the time of initial registration.

The only faculty members who may, by virtue of their appointment, automatically be the formal advisors-of-record for graduate projects or independent study activities (ISGs, theses, dissertations, etc.) are:

1. Tenure/tenure track faculty,
2. Professors of practice, or
3. Others who have at least a half-time, full-year faculty appointment, with advising of independent work as part of their contractual load.

Individuals holding other faculty appointments, such as part-time adjuncts or non-instructional research professors, may co-advise and indeed are encouraged to do so where appropriate.

Department heads wishing to authorize anyone with appointments other than these three categories as an advisor of record for projects, theses, or independent studies must first obtain agreement from the Dean of Graduate Studies. (In their absence, please refer the request to the Associate Provost for Academic Affairs.)

Students may switch advisors-of-record with approval from their department or program. The Office of Graduate Studies can provide guidance and assistance to graduate students considering a switch.

Plan of Study

After consultation with and approval by the advisor, each admitted student must file a formal Plan of Study with the department within the first semester if full-time, and within the first year if part-time. Program changes are implemented by advisor and student. Copies of the revised Plan of Study will be maintained in department files.

Commencement Participation Policy

Master's degree graduate students who are planning to complete their final courses (maximum 6 credits) in the summer term and graduate in September are eligible to participate in the previous May Commencement ceremony. Students who have thesis requirements remaining are not eligible. Students must be registered for all remaining requirements in the summer term by April 1 of the year they will be participating in order to be approved. Students may only participate in one ceremony per degree level. Students approved to walk will not receive their diploma, nor will the degree be conferred, at the May ceremony. They will also not be listed in the Commencement program. PhD students must complete all requirements before participating in a Commencement ceremony and are not eligible to participate in an earlier ceremony. No exceptions will be made to this policy.

Enrollment and Registration

The basic requirement for enrollment in a given course is a bachelor's degree from an accredited institution in a relevant field of science or engineering. Although those with management backgrounds may enroll in graduate management courses, no prior management study is required. Persons who have been admitted to graduate study at WPI are given first priority in course registration. Persons not holding a bachelor's degree, but who might qualify through training or experience, may be allowed to enroll on either a credit or audit basis with permission of the instructor. Registration for graduate courses is on a space-available basis for nonadmitted students.

Graduate students are expected to enroll in graduate courses or thesis credit on the registration days designated in the WPI academic calendar. Registration on days not designated will result in additional fees.

Enrollment in a course or courses, and satisfactory completion of those courses, does not constitute acceptance as a candidate for any graduate degree nor does it indicate admission to any graduate program. For students seeking advanced degrees, or graduate certificates, formal admission to a graduate program is required.

International Students

International students are required to enroll no later than the final day of the add/drop period. Students must be enrolled by this time in order to be registered in the SEVIS database and to remain in legal immigration. Failure to enroll in a timely manner could jeopardize a student's legal status and ability to lawfully remain in the U.S.

Degree-Seeking Student Enrollment

Graduate students must be registered for the semester in which degree requirements are completed. For master of science programs requiring a thesis and all Ph.D. programs, students must register for a minimum of 1 semester credit hour. For master of science programs that do not require a thesis, all students must be registered for all remaining credits in the final semester of study.

Full-time degree-seeking graduate students are expected to be continuously registered during their graduate school careers, excluding the summer semester. Full-time degree seeking students who interrupt their studies and are not on an approved leave of absence will be marked 'inactive' in any fall or spring semester in which there is no registration or credit activity. Inactive status means that students do not have access to WPI buildings, services or coursework.

In recognition of the competing responsibilities faced by part-time students, WPI allows one semester without credit activity to elapse before active status is revoked. Part-time degree-seeking graduate students will be marked inactive if one semester elapses with no credit activity and the registration period of the subsequent semester ends without registration or credit activity.

Inactive students will need to complete a readmission form through the Registrar's Office. See "Readmission from Leave of Absence" section below.

Official Withdrawal

Students who wish to terminate their degree programs must complete the Graduate Withdrawal Form available on the Registrar website and submit it to the Registrar's Office. Any registrations in semesters or terms that have begun before the certified date of last attendance will receive a grade of W and the student will be exempted from academic review. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. For official start dates of semesters and terms, see the Academic Calendar. For tuition adjustment information, see the "Tuition and Fees" section.

Students who have attended through the 12th week of a semester (or the 5th week of B or D terms) may not withdraw for that semester and will be academically reviewed. They may withdraw for the following semester.

Note: This applies to students officially withdrawing from the University; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Institutional Leave of Absence

Full-time students who wish to take a temporary leave from their degree programs and part-time students who wish to take more than one contiguous semester off must complete the Leave of Absence Form available on the Registrar website and submit it to the Registrar's Office. Students should inform themselves about consequences to financial aid, visa status, housing, and other considerations before taking an institutional leave of absence. Any registrations in semesters or terms that have begun before the certified date of last attendance will receive a grade of W and the student will be exempted from academic review. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. For official start dates of semesters and terms, see the Academic Calendar. For tuition adjustment information, see the "Tuition and Fees" section.

Students who have attended through the 12th week of a semester (or the 5th week of B or D terms) may not take a leave of absence for that semester and will be academically reviewed. They may take a leave of absence for the following semester.

Note: This applies to students taking a full leave from the University; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Readmission from Leave of Absence

To return, a student must fill out the Graduate Readmission Form available on the Registrar website and submit it to the Registrar's Office with all required signatures at least 30 days prior to the start of the semester in which they plan to return.

Military Leave of Absence

WPI graduate students who are called to active duty by the United States military shall receive a 100% refund for the uncompleted semester at the date of the notice. If such students have a loan obligation to WPI they will be granted an in-school deferment status during the period of active duty service, not to exceed a total of three years. To initiate the process to be classified "on leave for military service," a student must fill out a Leave of Absence form available on the Registrar website indicating that he/she is requesting school deferment status while being called to active duty. A copy of the official call to active duty notice from the military must be included with this request and be submitted to the Registrar's Office.

If the student has paid a tuition bill with proceeds from either a subsidized or an unsubsidized Federal Stafford Loan and has received a refund for either or both of the loans, the student shall be responsible for any overpayment of funds. It is therefore necessary for the student to contact the lender(s) upon withdrawal.

Childbirth and Adoption Accommodation Policy

In recognition of the challenges of balancing the demands of graduate study and parenting a new child, the Childbirth/Adoption Accommodation Policy aims to improve the environment for student parents. An Accommodation can be taken based on the student's individual circumstance in consultation with their Advisor and the Dean of Graduate Studies; early consultation will provide the time necessary to rearrange teaching duties for those students supported by teaching assistantships, or to adjust research/lab schedules. The purpose of this policy is to make it possible for a student to maintain registered full time student status, along with all the benefits of such status, while facilitating the return to full participation in courses, research and teaching.

Special note for TAs/RAs/Fellowship Students: During the Childbirth/Adoption Accommodation period, expectant graduate students who have been funded for the previous twelve (12) months through WPI internal TA/RA/Fellowships and who have received an award letter indicating continuing support will be eligible for salary continuation. During this timeframe, duties typically performed by TA's and RA's will be suspended for (eight weeks) and the student will not be expected to work. If the student parent is a teaching assistant, the Office of Graduate Studies will fund a temporary replacement for the affected period if necessary.

Requesting Leave: Matriculated and enrolled graduate students may formally request a Childbirth/Adoption Accommodation by emailing the Office of Graduate Studies. The student will be provided with a Childbirth/Adoption Accommodation Request form and will need to follow the appropriate procedures and documentation required. This Academic Accommodation Period is not a leave of absence from University responsibilities. The expectation is that the woman will be in residence, and assuming good health of the pregnant woman or new mother and the infant, will remain engaged in classwork and research.

Graduate Internship Experience

Graduate internship experiences are available across several programs of studies at WPI in order to enhance the professional development of Masters and Doctoral students. The graduate internship is a short-term and temporary work assignment in residence at a company or other *external* organization that forms a complementary part of a student's educational program. An internship will appear on the transcript with a minimum of 0 credits and a maximum of 3 credits (as determined by the department/program). All students require the approval of their faculty advisor-of-record to participate in an internship. Furthermore, the student and their faculty advisor-of-record will define concrete performance metrics and objectives to be achieved during the internship prior to the experience.

The graduate internship experience must align with the student's plan of study and be related to the specific graduate degree program. Because the purpose of an internship is to provide a student with a new experience, graduate students already employed full-time or part-time may not participate as interns at the same place of employment without program approval. Since the internship must be performed at an external site, WPI would not be considered an acceptable sponsor for a graduate internship. Typically, Teaching Assistants may not be on internship during the same time period during the academic year as when they are serving as a TA, but may pursue an internship over the summer or with departmental/program permission.

The graduate internship is not a University requirement, but rather an option available to all graduate students enrolled in graduate programs that permit internships. Students may pursue graduate internship experiences of up to 3 credits per degree (as determined by the department/ program). Internship experiences may be completed for 0-3 credits, and multiple internship experiences across semesters may be completed. However, graduate students may be enrolled in internships during a maximum of 3 semesters, inclusive of the summer, regardless of the amount of credit assigned per internship experience. Students must formally register for an internship for each semester they will be participating in an internship experience, even if the internship spans multiple semesters. Students enrolled in full time internships, defined as more than 20 hours per week, will be deemed a full-time student for that semester. Students enrolled in part time internships, less than 20 hours, will still need to be registered for 8 or more credits, inclusive of the internship's credits, to be considered fully enrolled. For-credit internship experiences are only for matriculated students. Graduate internships may not be applied to multiple degrees (i.e., BS/MS). Resources for graduate internships and job search tools are highlighted in the Career Development Center subsection in the Graduate Catalog. Enrollment in the graduate internship experience must adhere to established add/drop deadlines. For more information about graduate internship policies and procedures, including how to register for graduate internships, please see https://www.wpi.edu/academics/graduate/internships.

For Masters Students: Students enrolled in a Master's program may participate in the graduate internship experience after successfully completing their first 12 credits of graduate coursework at WPI, provided they are in good academic standing. If returning for a new degree after time away from the university, double counting credits from previous WPI degrees will not count towards the 12 credit threshold needed to be eligible to register for a graduate internship. With approval of the program designee, Master's students participating in a graduate internship should register for the graduate internship course designated 5900.

For PhD Students: Students enrolled in a PhD program may participate in the graduate internship experience after successfully completing their first 12 credits of graduate coursework at WPI, provided they are in good academic standing. If returning for a new degree after time away from the university, double counting credits from previous WPI degrees will not count towards the 12 credit threshold needed to be eligible to register for a graduate internship. With approval of the program designee, PhD students participating in a graduate internship should register for the graduate internship course designated 6900.

Special Notes for International Students:

An international graduate student on an F-1 visa must maintain full-time status for the duration of their graduate program. International students with F-1 visa status may apply for two types of practical training:

1. Curricular Practical Training (CPT): CPT is used for graduate level internships while students are pursuing their degrees. CPT is authorized by the university and the requirement is that the internship is an integral part of an established curriculum. Internships should be for credit.
2. Optional Practical Training (OPT): OPT is typically used by students for one year of employment after completion of degree. It can also be used in part for summer jobs or part-time employment during the academic year if employment is in the student's field of study. OPT requires approval by U.S. Customs and Immigration Services.

Non-degree Student Enrollment

Individuals with earned bachelor's degrees may wish to enroll in a single course or a limited number of courses prior to applying for admission. Non-degree students may choose to be graded conventionally (A, B, C), or on a pass/fail basis. Pass/Fail grading must be chosen at the time of registration, and courses taken on the pass/fail basis are not transferable to any master's degree program.

Non-degree students may take a maximum of 6 credits and receive letter grades in most departments. Once this maximum of 6 credits is reached, additional course registrations will be changed to pass/fail and will not be used for degree credit.

The fact that a student has been allowed to register for graduate courses (and earn credit) does not guarantee that the student will be admitted to that department's certificate or degree program at a later date. Students are therefore encouraged to apply for admission to a degree or certificate program prior to any course registration.

Non-degree Student Course Registration

Nondegree-seeking students register for courses in the same manner as all other students. However, degree-seeking students have preference in registering for courses with limited enrollments. Non-degree graduate students are considered active only in those semesters during which they have a current registration and credit activity. They are marked as inactive in the semester following the conclusion of their credit activity, including the summer semester, provided there is no new registration.

Auditing Courses

Graduate students primarily interested in the content of a particular course may register as auditors. Students are charged a 50% reduced tuition rate per semester hour to audit a course. There is no credit and no grade awarded for classes that are audited. Students cannot audit thesis and project work.

Audit registrants are encouraged to participate in the courses, but typically do not submit written work for evaluation. Often professors will accept written work of audit registrants, but this is left to the discretion of the instructor.

A student may change from credit to audit registration, but may not change from audit to regular credit registration. To change to audit registration for any graduate course, the student must complete an audit form (available in the Registrar's Office) within the first three weeks of class. No tuition or fees will be returned to students who change to audit registration, i.e., the full tuition rate applies.

Definition of Full-Time and Part-Time Status

If a student is registered for 8 or more credits, the student is deemed to be a full-time student for that semester. If a student needs fewer than 8 academic credits to complete degree requirements, registration for the number of credits required for completion of the degree gives the student full-time status. A student pursuing a master's degree, whose Plan of Study shows completion of all degree requirements within a single two-year period, retains full-time status so long as the student complies with that Plan of Study. A student officially enrolled in a graduate internship program has full-time status during the internship period. If a student has completed the minimum number of credits required for a degree, and is certified by the department or program to be working full-time toward the degree, enrollment in 1 credit of dissertation research for a student seeking the doctorate establishes full time status. For students seeking a master's degree, 1 credit of thesis research establishes the student's full-time status with department certification. For the purposes of this rule, the semesters are fall and spring.

Transcripts

Transcripts may be requested, and there is a fee associated with each transcript. For more information, please visit www.wpi.edu/+registrar.

Course Changes

There is an add/drop period at the start of each term and the exact deadlines depend on whether the course follows a 7-week schedule or a 14-week schedule.

For 7-week courses (undergraduate and graduate), a student can add a course without a fee through the fifth day of classes. On the sixth through the tenth day of classes, students can add courses (with instructor approval) with a $100 late fee. Students can drop courses on days 1-10 of each term without incurring a late fee. For undergraduates in 7-week courses, no adds or drops are allowed after the tenth day of the term. For graduate students in 7-week courses who drop a course after the tenth day, but before the end of the fifth week of the term, a W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16).

For 14-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the tenth week of the semester, and a grade of W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16). Consult the University calendar for specific dates.

For 10-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the seventh week of the semester, and a grade of W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16)

Note: If a degree-seeking student is dropping or withdrawing from all registered course activity, they must either take an institutional leave of absence or officially withdraw from the University.

Directory Information and Release of Information

The items listed below are designated as "Directory Information" for each student: campus mailbox, full name, year, major, advisor, e-mail address, permanent address, local address, local phone, photograph, date and place of birth, dates of attendance, enrollment status, degrees and awards received, and most recent or previous educational agency or institution.

Under the provisions of the Family Educational Rights and Privacy Act of 1974 (FERPA), the institution is permitted to release Directory Information without a student's consent. A student, however, has the right to restrict the disclosure of any or all of their Directory Information. Written notification to withhold Directory Information must be received by the Registrar's Office during the first week of the fall semester/A term. Forms are available in the Registrar's Office or on the Registrar's website. A request to restrict the disclosure of Directory Information does not restrict internal use of such by the institution.

Tuition and Fees

Tuition for all courses taken by graduate students is based on a $1,610 fee per credit hour for the 2021-2022 academic year. The Graduate Student Organization Fee is $30.00 for full-time students and $15.00 for part-time students each semester. Health & Wellness fee may be charged for on campus students. See https://www.wpi.edu/offices/bursar/tuition for current tuition and fee information.

Tuition Adjustments for Leaves and Withdrawals

Tuition adjustments will follow the schedule below, based on the certified last date of attendance, for Institutional Leave of Absences and Official Withdrawals. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. Weeks are counted from the official start date of the semester.

Last Date of Attendance During:	Tuition Adjustment %
Week 1	100%
Week 2	100%
Week 3	80%
Week 4	60%
Week 5	40%
Week 6	20%
Week 7 and after	0%

Note: This applies to students taking a leave of absence or officially withdrawing from the institution; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Audit Rate

A 50% reduced tuition rate per semester hour for the 2021-2022 academic year is available for those who wish to audit a course. Audit registration cannot be changed to credit once the semester has started.

Tuition Payments & Billing

WPI sends electronic bill statements (eBill) to the WPI email address assigned to each student. Bills are sent in the fall and spring semesters. It is important to view each new eBill you receive as changes could have occurred in your account.

Tuition must be paid in full by the specified due date on the electronic bill (eBill) statement. Students that register within one week prior to the eBill due date are required to pay at the time of registration. Students remit payment online with a checking account (no fee) or via credit card (2.75% fee). For international credit card or domestic and international wire payments visit https://www.flywire.com/school/wpi. For information on the eBill process or payment options, please visit www.wpi.edu/+bill.

Late Fees

Late fees of up to $250 will be assessed on balances and accounting holds will be placed on accounts. The first late fee is assessed after the initial due date for the bills, the second is typically assessed mid semester for outstanding balances. WPI fully supports the Veterans Benefits and Transition Act of 2018. Sec. 103 amends US code to prevent schools from penalizing Ch. 31 or 33 students if/when the VA is late making payments. WPI policy supports and agrees to the VA recommendations of the following while waiting for VA payments: WPI agrees to not prevent enrollment, charge a late penalty fee(s), require alternative or additional sources of funding or deny access to school resources

Monthly Payment Option

A monthly payment plan is available for each semester. Payments will be divided into equal monthly payments. There is an annual or semester enrollment fee for use. However, there are no additional charges or interest (late fees or returned payment fees may apply). For more information, contact the Bursar's Office at www.wpi.edu/+bill.

Health Insurance

All full-time graduate students must be covered by health and accident insurance equivalent to that offered under the WPI Student Health Insurance Plan. Students must complete a waiver form online annually if they wish to not purchase the WPI offered plan. Optional coverage for a spouse or dependent is available.
Please contact the Bursar's Office
www.wpi.edu/+bill for further information.

Visit us any time at: www.wpi.edu/+registrar

Degree Requirements

The following are WPI's minimum requirements for advanced degrees. The general requirements for all advanced degrees must be satisfied to earn any advanced degree. The additional requirements for specific degrees must be satisfied in order to earn the specified degree, - regardless of the field in which the degree is earned. Please review department requirements for more specific information.

General Requirements for All Advanced Degrees

All degree requirements must be satisfied before the degree is awarded. Exceptions to general and specific degree requirements or to other rules may be made, but only by the Committee on Graduate Studies and Research (CGSR).[1] Requests for exceptions are to be made by written petition to that committee.

At the time the degree is awarded, the student must have been admitted to the graduate program of the degree-granting program. Administratively, a degree-granting program may be a department or a program.

A minimum of two-thirds of the required graduate credit for an advanced degree must be earned at WPI.

All degree and certificate programs require a minimum program GPA of 3.0.

In applying for graduation, the student must specify by year which graduate catalog contains the rules being satisfied. These rules may be those in place on the date of the student's matriculation, those in place on the date of the student's application for graduation, or those in place in a single graduate catalog in effect between the dates of matriculation and graduation.

After the Application for Degree is submitted, all advanced degrees are subject to the final approval of the Registrar's Office, which determines if the student has satisfied the letter and intent of the requirements for advanced degrees.

The Registrar's Office submits a candidates list to CGSR who make their recommendations for the approval of advanced degrees to the faculty of the institute, which in turn recommends to the president and trustees for their final approval the names of students who should be awarded advanced degrees.

Requirements for the Master of Business Administration and Master of Mathematics for Educators appear under the descriptions of the awarding programs.

General Requirements for the Master of Science and Master of Engineering

The student must obtain a minimum of 30 credit hours of acceptable course, thesis or project work.

If a thesis is required by the student's program, it must include at least 6 credit hours of research directed toward the thesis, in a project resulting in the completion of an M.S. thesis.

A student completing a master's degree with a thesis option is required to make a public presentation of the thesis. Departments may, at their option, extend the - presentation to include a defense of the thesis.

The student must obtain a minimum of 21 credit hours of graduate level courses or thesis (18 credit hours for students in the Combined Bachelor's/Master's Program), including at least 15 credit hours of graduate level courses or thesis in the major field of the student. Other courses (to make up the minimum total of 30 credit hours) may include advanced undergraduate courses approved by the student's program. Such courses are normally considered to be those at the 4000 level. The use of advanced undergraduate courses for satisfaction of graduate degree requirements must be approved by the student's program. A 1/3-unit WPI undergraduate course taken for graduate credit is assigned 2 credit hours of graduate credit. A graduate student registered for graduate credit in an undergraduate course may be assigned additional work at the discretion of the instructor.

General Requirements for the Doctorate

The student must demonstrate to the faculty high academic attainment and the ability to carry on original independent research.

The student must complete a minimum of 90 credit hours of graduate work beyond the bachelor's degree, or a minimum of 60 credit hours of graduate work beyond the master's degree, including in either case at least 30 credit hours of research.

The student must establish residency by being a full-time graduate student for at least one continuous academic year.

The student must attain status as a doctoral candidate by satisfying specific degree requirements in the student's field.

The student must prepare a doctoral dissertation and defend it before a Dissertation Committee, at least two of whose members must be from the student's program and at least one of whose members must be from outside the student's program. After a successful defense, determined by a majority vote in the affirmative by the Dissertation Committee, the dissertation must be endorsed by those members of the Dissertation Committee who voted to approve it. The completed dissertation must follow in format the instructions published by the library (see page 22). After final approval for format of the dissertation, the Provost will notify the Registrar that the dissertation has been approved.

Once a student has satisfied the departmental candidacy requirements, the student will be permitted to enroll for dissertation credits. Prior to completion of candidacy requirements, a student may enroll for no more than 18 credits of directed research.

General Requirements for the Combined Bachelor's/Master's Degree Program

Only registered WPI undergraduates may enter the Combined Bachelor's/Master's Program. To enter, a student must submit an application and required support materials to WPI's Office of Graduate Admissions, preferably in the junior year. Admission to the combined program is made by the faculty of the program that awards the graduate degree. A student in the combined program continues to be registered as an undergraduate until the bachelor's degree is awarded.

While in the combined program, a student may continue to enroll in courses or projects toward the undergraduate degree; the student may also register for graduate courses, projects, directed research or thesis credits toward the master's degree.

A student in the combined program may, within the program limit and with prior approval, use a limited number of the same courses toward the bachelor's and master's degrees. The limitation is computed from the graduate credit hours for each course. Courses whose credit hours total no more than 40% of the credit hours required for the master's degree, and which meet all other requirements for each degree, may be used to satisfy requirements for both degrees. Such courses are recorded on the transcript using the credit hours/ units and grades appropriate at the graduate or undergraduate levels. For students in the combined program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 2 credit hours. Graduate courses applied toward the undergraduate degree are awarded undergraduate credit with a conversion rate of 1 credit hour = 1/6 undergraduate unit.

Students in the combined program may use advanced undergraduate courses to satisfy graduate degree requirements. The academic department decides which courses may be used in this way. Faculty members teaching these advanced undergraduate courses may impose special requirements.

If the programs awarding the bachelor's and master's degrees are not the same, the program awarding the graduate degree may require that the student's major qualifying project relate in some way to the graduate program's discipline. The graduate program may also make other requirements as it deems appropriate in any individual case. Additional requirements appear within each department's section in this catalog.

To obtain a master's degree via the combined program, the student must satisfy all requirements for that master's degree. To obtain a bachelor's degree via the combined program, the student must satisfy all requirements for that bachelor's degree.

The time limit for completing the combined program varies by department from one to four years. See department description for full information.

Limitation of Time to Complete Degree

Students must complete degree requirements within the following timelines:

Degree	**Time-Limit**
Graduate or Advanced Certificate	Within 3 years of matriculation
Master's Degree (M.S., MENGR, MME)	Within 5 years of matriculation

Degree	Time-Limit
M.B.A.	Within 7 years of matriculation
Ph.D.	Within 10 years of matriculation

Approved leaves of absence do not stop the clock for the completion of the degree. Students who require more time to complete their degree must petition the Dean of Graduate Studies to continue.

Transfers and Waivers

A student may petition to use graduate courses completed at other accredited, degree-granting institutions to satisfy WPI graduate degree requirements. A maximum of one-third of the credit requirements for a graduate degree may be satisfied by courses taken elsewhere and not used to satisfy degree requirements at other institutions.

Students should submit their petitions to their academic department or program; once they are approved they are filed with the Registrar.

To ensure that work completed at other institutions constitutes current practice in the field, a WPI program may set an expiration date on transfer credit. After this date, the course may not be counted towards a WPI degree.

Transferred courses are recorded on the student's WPI transcript with the grade CR and are not included in the calculation of grade point averages. Grades earned in Biomedical Consortium courses, however, are recorded on the transcript as if they were taken at WPI itself.

A student who withdraws from a graduate program and is later readmitted may apply courses and other credits completed before the withdrawal toward the degree. The admitting program will determine at the time of readmission which courses taken by the student may be applied toward the degree and the latest date those courses may be applied. There is no limit, other than that imposed by the program, on the number of credits a readmitted student may use from prior admissions to the same degree program.

With the appropriate background, a student may ask permission to waive a required course and substitute a specified, more advanced course in the same discipline. Requests are subject to approval by the student's program and must be filed with the Registrar within one year of the date of matriculation in the program. A program may waive (with specified substitutions) up to three required courses for a single student.

Acceptability of Credit Applicable to an Advanced Degree

Graduate level credit, obtained from courses, thesis and project work, may include:

- Coursework included in the approved Plan of Study.
- Coursework completed at the graduate level and successfully transferred to WPI from other accredited, degree-granting institutions (see Transfers and Waivers).
- Graduate coursework completed at the undergraduate level at WPI and not applied toward another degree.

A maximum of one-third of the credit requirements from one graduate degree, either completed or in progress, at WPI may be used in partial fulfillment of the requirements for another graduate degree at WPI.

No credit may be triple counted for any degree at any level of study.

1. CGSR—The Committee on Graduate Studies and Research (CGSR) is concerned with all post-baccalaureate programs of the University, and reviews and recommends changes in WPI policies on goals, student recruitment, admissions, academic standards, teaching and research assistantships, scholarships and fellowships. It also makes recommendations to the faculty and administration on new graduate programs and courses, and changes in programs and courses. The committee acts on admission of graduate students to degree candidacy, dismissal for failure to meet academic standards, and student petitions on academic matters. It brings to the faculty for action the names of students whom it has determined are eligible for post-baccalaureate degrees. The committee reviews and recommends changes in policy on the funding, promotion and conduct of research at WPI.
2. GPA—The Grade Point Average (GPA) is calculated as the sum of the products of the grade points and credit hours for each registered activity, in the average, divided by the total number of credit hours for all registered activities in the average. Grade points are as follows: A = 4.0; B = 3.0; C = 2.0; D = 1.0; and F = 0.0.

Theses and Dissertations

WPI is a member of the Networked Digital Library of Theses and Dissertations. This organization is dedicated to "unlocking access to graduate education" by making the full text of theses and dissertations available online.

Students are required to submit an electronic version of their thesis or dissertation entirely through the web. Submission deadlines throughout the year are published in the Registrar's calendar, https://www.wpi.edu/offices/registrar/calendar. Students should consult with their department/program for any defense scheduling deadlines and policies, but at a minimum should plan to hold their defense no later than 3 weeks before an ETD submission deadline to allow adequate time for any ETD revisions before final submission.

Most submitted theses and dissertations will be made available to the general public via the web, but individual authors and their advisors may choose to temporarily restrict access to their works based on factors that include confidentiality and intellectual property. Students should discuss these issues thoroughly with their advisors and committee members as early in the process as possible.

The following are required for proper submission of electronic theses and dissertations (ETDs):

1. Approval Form (Signatures). This can be a scanned copy of your signed thesis signature page, or it can be a digitally signed form that includes your thesis title, degree, date, and committee members. A form for collecting digital signatures is available on the ETD submission information page. You will submit the signed Approval Form to the Registrar's Office through the eProjects submission system as you submit your thesis.
2. Your thesis or dissertation, converted to a single PDF file and uploaded via eProjects. If you have additional files or appendices, these should be added as separate supplementary files rather than submitting your thesis as a PDF portfolio. Students will receive a confirmation from the eProjects ETD submission system once it has been accepted. The Registrar's Office will be notified simultaneously of the ETD confirmation.

Extensive information about creating and submitting ETDs is available on the web at: http://www.wpi.edu/+etd

Thesis Binding

Students and departments may wish to retain a bound paper copy of theses and dissertations. Information on thesis binding can be found online at http://www.wpi.edu/+etd

Student Services

Facilities and Services

Bookstore

The bookstore, located on the second floor of the Rubin Campus Center, is open during the first days of classes from 8:00 a.m. to 7 p.m. During the rest of the school year, hours of operation are 8 a.m. to 7 p.m. Monday through Thursday, 8 a.m. to 5 p.m. Friday, and 11 a.m. to 5 p.m. on Saturday.

Textbooks for off-campus courses may be purchased at the first meeting of each course. Payment may be made by cash, check or credit card. Additionally, textbooks may be purchased online at http://wpi.bncollege.com.

For more information please call (508) 831-5247 or e-mail bkswpi@bncollege.com.

Student Health Center

In addition to purchasing health insurance, graduate students may also make use of WPI's Student Health Center for an annual fee of $370 . By choosing this option, you can have a doctor at the Center serve as your primary care physician. You may also then use the center on a walk-in basis during its normal hours (weekdays 8:00am to 5:00pm). You can learn more about WPI's Student Health Center at www.wpi.edu/+Health.

WPI Police

Personal safety information, security practices at WPI and the University's crime statistic information can be obtained by visiting the campus police Website. Students can also obtain a copy of the University's "Right To Know" brochure by contacting the WPI Police Department at 508-831-5433.

Graduate students are entitled to parking permits for an annual fee. Parking is on a first-come, first-served basis. Parking is also available on the city streets surrounding the campus. Be sure to obey parking signs, as enforcement in Worcester is strict. The city's winter parking regulations are available on the WPI police website, as well.

Decals may be purchased at the WPI Police Department located at Founders Hall in the Lower Level. WPI Police also has prepared a brochure on parking regulations that is available on-site or online at https://www.wpi.edu/offices/police/parking-traffic.

Career Development Center

The Career Development Center (CDC) at WPI assists graduate students in the development of lifelong skills related to careers and the job search process. The CDC provides resources and support to graduate students on resume/CV writing, cover letter critiques, internship and job search strategies, interviewing skills/mock interviews, advanced degree pursuit, career advising, job offer evaluation and negotiation skills, and more. Support to graduate students is available through appointments with a CDC staff member, walk-ins, and workshops. For distance students, telephone and Skype appointment options are available. The CDC is available for lifetime service and support to alumni, free of charge.

Every graduate student has a Job Finder account to search for companies and jobs, gain access to subscription resources (Career Shift, Going Global, Career Search, MyPlan), access upcoming workshops and corporate events, and more. All appointments are scheduled through Job Finder, via "Request an Appointment" in the Shortcuts menu.

Internship Resources

Resources are available at the Career Development Center (CDC) for graduate students seeking graduate internship experiences during their studies at WPI. The CDC maintains an extensive database of companies and other external organizations interested in supporting graduate students in their professional development via internships. All WPI students have access to this database, as well as the ability to apply to posted opportunities. To find out more, please contact the CDC.

To contact the CDC, call 508-831-5260, email cdc@wpi.edu, or visit us at the Project Center, Lower Level.

Class Cancellation

When all classes are cancelled (severe weather during the midday period, forecast to last through evening) cancellation will be broadcast on radio stations WTAG, WSRS, WAAF, WFTQ, WKOX and WBZ. Information will also be posted on the university website and on the cancellation hot line at 508-831-5744.

Information Technology Services

WPI Information Technology Services offers a wide range of information technology resources to the WPI community to support teaching, learning, research and student life.

Access

The WPI computer account acts as the graduate student's WPI virtual identity while the student is actively registered. Usage is governed by the Acceptable Use Policy. The account provides access to many technology resources including:

Network

- Wired and wireless network available in all academic buildings, residence halls, and participating Greek houses
- High speed Internet connectivity including connection to Internet2
- Virtual Private Network (VPN) provides secure remote access to WPI on-campus information technology resources
- Information Security monitors the WPI network and provides data malware protection

University Systems

- University services, such as email, learning management system, eProjects, web site, software applications, remote desktop, databases, etc. are enabled by System Operations and Web Development teams.
- Workday, and related data systems, enable administrative departments to run the critical business functions of the University . They provide students and faculty access to student registration, advising, and financial information . They also enable students to update their biographical information, set proxy, and check grades.

Software

Students can access numerous software applications including academic courseware:

- in public computer labs
- via remote services
- via network download for some applications
- discounted purchase via online store

Computer Labs

Over 700 public computers are available across campus for student use. Many are located in open access labs within academic buildings and throughout the Gordon Library. Public computer labs offer a consistent user interface and software profile. Specialty labs for students include:

- Multimedia Lab and Shuster Digital Scholarship Lab enabling high-end digital editing, scanning, and GIS are available in the Gordon Library
- Maker space, prototyping and recording labs are housed in the Foisie Innovation Studio
- Design Studio offers powerful workstations for CAD/FEA/FEM projects and coursework in Higgins Labs

Printing Services

The Gordon Library Information Commons Print Center is available to meet students' scanning and printing needs. Printers are also located throughout the Gordon Library as well as within some computer labs. For additional printing services listed below see Technology Support and Instruction:

- Large-format poster printing
- Rapid prototyping/3D printing

Collaboration and Learning Resources

Collaboration and learning are supported through specialized software and applications, technology-enhanced spaces, and equipment loans.

- Learning Management Software: Canvas course web sites
- Tools: Office 365 (email/calendar/contact, task, document management), Microsoft Teams for video/audio and chat
- Web-conferencing: Zoom allows remote participants to conduct meetings in real-time in a web-based environment from any location with a web-enabled device and a high speed Internet connection
- Tech Suites: Technology-enhanced meeting spaces with wireless screensharing designed for student project group use
- Learning Spaces: Active learning classrooms, electronic classrooms, and electronically enabled conference rooms
- Equipment Loans: Laptops, digital cameras, audio recorders, hard drives, projectors, etc.

Technology Support and Instruction

Technology Service Desk

Gordon Library, Main Floor; (508) 831-5888; its@wpi.edu; https://hub.wpi.edu

- In-person or remote technology support provided
- Requests for assistance can be submitted via phone, email or web
- IT Service, Software, and Knowledge Catalog provides answers to common issues

Academic Technology Center

Fuller Labs, Room 117; (508) 831-5220; atc@wpi.edu

- In-person technology support on audio-visual equipment loaned out for multi-media projects and campus events sponsored by WPI student organizations
- Large-format poster printing

Academic and Research Computing

Higgins Labs, https://www.wpi.edu/research/resources/support/academic-research-computing

- Instructor-led scientific and engineering software applications training
- Data management and access to cloud collaboration space
- Numerous high performance computational resources available for student research projects
- Large-format poster printing located in Higgins Labs
- Enterprise level rapid prototyping/3D printing located in Higgins Labs

Gordon Library

The George C. Gordon Library is open over one hundred hours each week during the academic year. The library provides resources and innovative services in support of teaching, learning and scholarship at WPI.

The library's collections support the curriculum and research needs of the WPI community. The library offers an extensive collection of print and electronic journals, over 1.3 million academic ebooks, and several hundred research databases which support all areas of the WPI curriculum. The library collection also includes all graduate theses and dissertations through 2004, with all those from 2002 available online through Digital WPI (https://digital.wpi.edu). Music CDs, DVDs and other media, and bestsellers and newspapers are available for educational and recreational purposes. The library's Archives and Special Collections department includes the historic records and artifacts of the university, rare books, manuscripts, and artwork including major holdings of Charles Dickens's life and works; and a growing archive that documents WPI's history of invention and innovation in education and industry.

The library catalog, electronic journal and book collections, specialized research databases, course-specific information, and many other resources are available from the library's website (http://library.wpi.edu). The website features powerful search options and links to digital resources and services. Access to WPI users who are off-campus is available by logging into resources through the

WPI proxy service. This can be done through the library's website or by following instructions available at: https://www.wpi.edu/library/research/research-off-campus.

The staff of Gordon Library offers many services that support graduate students. Librarians can meet with students either as individuals or in groups for research consultations. Meetings can be scheduled via the library's website, or by emailing library@wpi.edu, and librarians are available to meet with remote learners via video conferencing software. Librarians also support graduate students in their roles as teaching assistants by providing library instruction and orientation sessions.

The staff of Archives and Special Collections works with students to access historical resources relating to WPI and the region.

Students can request any materials not held in Gordon Library through the interlibrary loan service. Requested journal articles can often be delivered electronically within a day or less. WPI students also have access to the collections of other academic libraries within Central Massachusetts with the library's membership in the Academic and Research Collaborative (ARC). Students can obtain an ARC cross-borrowing card (available at the library's front desk) which allows direct borrowing at many regional academic libraries.

Gordon Library information services, the Academic Technology Center, and the Technology Service Desk are conveniently co-located on the library's main floor. The adjacent Class of 1970 Library Café serves food and beverages, and follows the undergraduate academic year calendar.

The library's four floors contain a wide variety of individual and group study spaces. Tech Suites – collaborative work areas equipped with up-to-date screen-sharing technology – can be reserved for student group use. Additional group study spaces are located throughout the building, among them Studio@Gordon, an active and informal collaboration space on the ground floor. There are also computer workstations configured for group and individual use, many with large monitors for collaborative project work. The Multimedia Lab on the first floor offers specialized multimedia and GIS software and scanners. Adjacent to the Multimedia Lab are the Shuster Digital Scholarship Lab and the Anderson Lab. The Shuster Digital Scholarship Lab is equipped with scanning equipment, a document camera, collaborative work tables, projection screens, and six Dell Surface Studio 2 computer workstations. The Shuster Digital Scholarship Lab and the Anderson Instruction Lab can be used by student groups during evenings and weekends, and on weekdays when not booked for WPI training or course-related events. The library features both wireless and wired computer network access, and over 80 public-use computers.

Special exhibits including exhibits of work by WPI artists are offered regularly in the library's galleries, and WPI authors are regularly invited to talk about their work in the library's Meet the Author series. For more information please visit the library website at http://library.wpi.edu.

Housing

Most graduate students live in rooms or apartments in residential areas near the campus. A limited amount of on-campus housing may be available for single graduate students. Family housing is not available on campus.

The Office of Residential Services, 508-831-5645, provides information regarding both on-campus and off-campus housing. A listing of off-campus accommodations is available at www.wpi.edu/Admin/RSO/Offcampus/.

International Graduate Student Services

The Office of International Students and Scholars is located at WPI's International House at 28 Trowbridge Road. The office provides information and assistance on immigration and other regulatory matters, information on cultural and social programs and services, as well as general counseling.

With 1,472 international students from 85 countries (Fall semester, 2015), WPI is the embodiment of the diversity that characterizes the United States. The House serves as a venue for a variety of programs throughout the year, such as coffee hours, movies, Midnight Breakfast, lectures and other social and cultural activities. The House, which provides wireless access to the network, has several facilities available to students and scholars and student groups interested in international issues, including:

- International Seminar Room for discussion groups, meetings and ESL classes
- International Resources Room with cross-cultural material, travel information and ESL materials as well as computer access
- Lounge for students and visitors to relax and enjoy a cup of coffee or a game of backgammon
- Two guest rooms for temporary housing

Office of International Students and Scholars: 508-831-6030. ESL Director: 508-831-6033.

Mail Services

Located in the Campus Center, first floor.

Student Mail Room 508-831-5317,

Incoming/Receiving 508-831-5523,

Mail Processing 508-831-5317.

- Package pick-up
- Stamps sold
- Letters and packages weighed, metered
- Discounted Express Mail
- Fax services
- Limited number of mailboxes available

Printing Services

Located in Boynton Hall, lower level. Telephone 508-831-5842 or -5571.
Hours (Monday through Friday)
8 a.m. to 4:30 p.m.

- Offset printing
- Photocopying (including color)
- Binding of reports
- Laminating
- Print from disc, electronically sent files or hard copy

Sports and Recreation

The university provides a varied program of sports and recreation. Graduate students usually enter teams in several intramural sports and may participate in certain intercollegiate club sports as well as on-campus musical or theater groups.

The NEW Sports and Recreation Center presents an opportunity for the whole WPI community to be more active and practice healthier lifestyles.

The Sports and Recreation facilities includes a two-story fitness center with cardio equipment and free weights, a four-court gymnasium, a competition pool, dance studios, a three-lane jogging track, racquetball and squash courts. Graduate students frequently join faculty groups for noontime jogging, aerobics and basketball.

A wide variety of entertainment is brought to the campus, ranging from small informal groups to popular entertainers in the 3,500-seat Harrington Auditorium. A series of films is shown in Perreault Hall, and chamber concerts are presented in the Baronial Hall of Higgins House.

The normal social activities of a medium-sized city are readily accessible, many within easy walking distance. Other activities of interest to students are offered by the many colleges in the Worcester Consortium.

Student ID Cards

The WPI ID is also a student's library card and is used in many departments for lab access as well.

Students may also deposit money on their cards for use in the WPI dining locations at a 10% discount. The ID office is located in East Hall. The hours are: Monday through Friday 8 a.m. to 5 p.m. For information, call 508-831-5645.

Dean of Graduate Studies

The Dean of Graduate Studies is the principal advocate for graduate programs across all disciplines at WPI. Graduate students needing assistance with academic issues should reach out to the Dean's Office. The Dean and the Office of Graduate Studies manage offers of funding for graduate Teaching Assistants (TAs), Research Assistants (RAs), and graduate fellowships, oversees the distribution of graduate TAs, coordinates the annual graduate student orientations, and other major events for graduate students, the Graduate Research Innovation Exchange (GRIE) and the Three Minute Thesis (3MT®) Competition, organizes graduate student professional development programming, including the Student Training and Readiness Series (STARS), provides student success support to all graduate students, and serves as an advisor to the Graduate Student Government.

Dean of Students

The Dean of Students' office staff is available to students enrolled in all programs to assist with any out-of-the-classroom concerns that may arise. Staff members are available between 8:30 a.m. and 5 p.m. Appointments outside of these hours can be arranged by calling 508-831-5201.

Degrees
Aerospace Engineering

Faculty

Nikolaos A. Gatsonis, Professor and Department Head; Ph.D., Massachusetts Institute of Technology. Continuum and atomistic computational methods for fluids and plasmas, development of plasma diagnostics and microfluidic devices, spacecraft propulsion and micropropulsion, spacecraft/environment interactions.

John J. Blandino, Associate Professor and Undergraduate Coordinator; Ph.D., California Institute of Technology. Fluid mechanics and heat transfer in microdevices, plasma diagnostics, electric and chemical propulsion, propulsion system design for precision formation flying.

Raghvendra Cowlagi, Associate Professor; Ph.D., Georgia Institute of Technology. Autonomous mobile vehicles, motion planning and optimal control, hybrid optimal control with applications in aerospace engineering, formal methods for system safety and reliability.

Michael A. Demetriou, Professor and Graduate Coordinator; Ph.D., University of Southern California. Control of intelligent systems, control of fluid-structure interaction systems, fault detection and accommodation of dynamical systems, acoustic and vibration control, smart materials and structures, sensor and actuator networks in distributed processes, spacecraft attitude estimation and control.

Jagannath Jayachandran, Assistant Professor; Ph.D., University of Southern California. Combustion at engine-relevant thermodynamic conditions; ignition, propagation, and extinction of flames; transient phenomena in reacting flows; air-breathing propulsion; detailed modeling of low-dimensional reacting flows; optical and laser-based diagnostics.

Nikhil Karanjgaokar, Ph.D., University of Illinois at Urbana-Champaign: Experimental mechanics at micro/nano-scale, temperature and rate dependent mechanics of nanostructured materials, dynamic response and flow of granular media, mechanics and damage of inhomogeneous materials, optical measurement techniques.

David J. Olinger, Associate Professor, Ph.D., Yale University. Fluid mechanics, aero and hydrodynamics, fluid structure interactions, fluid flow control, renewable energy.

Mark W. Richman, Associate Professor, Ph.D., Cornell University. Mechanics of granular flows, powder compaction, powder metallurgy.

Zachary Taillefer, Assistant Teaching Professor. Ph.D. Worcester Polytechnic Institute. Electric Propulsion; Plasma Diagnostics.

Zhanxian Yuan, Assistant Professor, Ph.D., Georgia Tech. Aerospace structures, composite structures, structural dynamics.

Programs of Study

The Aerospace Engineering offers three graduate programs of study with the following degree options:

- The Master of Science (M.S.) program leading to the M.S. degree.
- The combined Bachelor of Science (B.S.)/Master of Science Program leading to the B.S. and M.S. degrees.
- The Doctor of Philosophy (Ph.D.) program leading to the Ph.D. degree.

Admission Requirements

For the M.S. program, applicants should have a B.S. in aerospace engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.). The requirements are the same for admission into the thesis and non-thesis options of the M.S. program. At the time of application to the master's program, the student must specify his/her thesis option (thesis or non-thesis).

For the combined B.S./M.S. program, students must be currently enrolled as WPI undergraduates in aerospace engineering or in a related engineering field. When applying to the B.S./M.S. program, students must specify their intention to pursue either the thesis or non-thesis M.S. option.

For the Ph.D. program, a B.S. or M.S. degree in aerospace engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.) is required. The Aerospace Engineering Program reserves its financial aid for graduate students in the Ph.D. program or in the thesis option of the M.S. program.

Degree Requirements

The AE degrees are based on coursework shown in Table 1 and research as shown in Table 2. There are five curricular areas of study: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures; General Aerospace Engineering Topics.

Laboratories and Facilities

Aerospace Engineering

MQP Laboratory
HL005 (AE Faculty)
This 450 sq. ft. facility supports Major Qualifying Project work associated with a number of different aerospace related projects. Workbenches provide the space required for assembly, integration, and testing of hardware, often with more than one student group working together on complex, interrelated projects.

Aerodynamics Test Facility

HL016 (Olinger)
This 975 sq. ft. laboratory houses a low-speed, closed-return wind tunnel, with a test-section of 2´´2´´8´. The tunnel speed is continuously variable up to 180 ft/s. The temperature in the tunnel can be controlled via a controller and a heat exchanger in the settling chamber. The tunnel is equipped with a two-component dynamometer. Aerodynamic flows are studied in this laboratory with the aid of traditional pressure, temperature, and velocity sensors, as well as advanced optical instrumentation. The test facility is used for graduate research and undergraduate projects.

Laboratory for Fluids and Plasmas

HL016, HL313 and
HL314 (Blandino, Gatsonis)
The Laboratory for Fluids and Plasmas (LFP) supports research and educational activities in electric and chemical micropropulsion, plasma diagnostics, and microfluidics. The LFP-016 covers 450 sq. ft and houses a 50 inch diameter, 72 inch long stainless steel vacuum chamber (T2), which enables the characterization of electric and chemical thruster component performance. The pumping system for T2 includes a rotary mechanical pump, positive displacement blower combination capable of providing substantial pumping speed (> 560 liters/sec) at low vacuum (10-2 - 10-3 torr). This pump pair can be used for tests requiring relatively high mass flow rates, such as plume measurements on micro-chemical thrusters. For tests of electric thrusters where lower pressures (higher vacuum) are required, a 20 inch cryopump is available which can provide up to 10,000 liters/s (on N2) at pressures in the low 10-6 torr range. A second, medium-sized vacuum chamber (T4), consists of a 29.75 inch diameter, 34.25 inch tall stainless steel bell-jar. T4 uses a Leybold TurboVac 361 turbomolecular pump backed by a Leybold Trivac D16B rotary-vane dual-stage mechanical pump. The turbopump is rated for a pump speed of 350 L/s on air at pressures in the low 10-6 torr range. Both T2 and T4 are equipped with multiple ports for electrical and optical access. The LFP is also equipped with a variety of ancillary instrumentation including power supplies and oscilloscopes as well as data acquisition and flow delivery hardware.

The LFP in HL313-314 covers 600 sq. ft. It houses two vacuum chambers and specialized test facilities for the investigation of onboard micropropulsion, electrospray sources (for both propulsion and nano-fabrication applications), plume/spacecraft interactions, microsensors, and microfluidics. The first chamber (T1) is an 18 inch diameter, 30 inch tall stainless steel bell-jar equipped with a 6 inch diffusion pump backed by a 17 cfm mechanical pump. The system is capable of an ultimate pressure in the low 10-6 torr range. The second vacuum chamber (T3), is a 22.5 inch diameter, 32 inch tall stainless steel bell-jar. It is equipped with a 6-inch diffusion pump backed by a Varian DS 602 dual stage rotary vane pump. The system is capable of achieving an ultimate pressure in the 10-6 torr range. T3 also includes a computer controlled probe positioning system. The system consists of micos linear (VT-80) and rotary (DT-80) computer-controlled stages to achieve precise, three degree-of-freedom positioning. In addition, T3 is equipped with a 3-centimeter Kauffman Ion Source with computer-controlled, mass flow delivery. For microfluidics research, the LFP includes equipment for studies of two-phase flows in microchannels. Imaging equipment for these flows includes a high-resolution monochrome progressive scan Pulnix-1325 camera with computer based image-capture and processing software. In addition, a portable fume hood work space is available for use in testing of dielectrophoretic flows with high vapor-pressure fluids. The LFP-314/313 includes a variety of tools and specialized instrumentation including a syringe pump, oscilloscopes, precision source meter, electrometer, and digital multimeters. Data from these instruments can be collected and stored on computer using a LabView based data acquisition system.

Computational Fluids and Plasmas Laboratory

HL236 (Gatsonis)
This 660 sq. ft. computational facility is used for graduate research and educational activities in computational methods and their applications to fluids, gases, and plasmas. CFPL provides students with access to Direct Simulation Monte Carlo, Particle-in-Cell, fluid dynamics, and MHD codes as well as visualization and data reduction software.

Fluid Dynamics Laboratory

HL311 (Olinger)
This 420 sq. ft. laboratory is used for research and educational activities in fluid dynamics. It houses a low

speed, low turbulence wind tunnel facility with a one-foot square test section which is used for experiments on low Reynolds number aerodynamics related to biologically inspired flight, and fluid-structure interaction. These systems are of practical importance in many aero- and hydrodynamic systems, such as micro-air vehicles and flow-induced vibration of flexible cables Standard equipment such as vibration shakers, hot-wire anemometry systems, spectral analyzers, digital oscilloscopes and data acquisition systems are also used in the laboratory.

Combustion Research Laboratory

HL026 (Jayachandran)

The Combustion Research Laboratory (CRL) is used for fundamental research and educational activities in laminar as well as turbulent, high activation energy reacting flows of relevance to aerospace propulsion and power generation. CRL is equipped with high pressure combustion facilities, high speed imaging, and laser based diagnostics.

Structures and Materials Laboratory

HL028, HL305 (Karanjgaokar)

The structures and material laboratory is used for undergraduate and graduate research in field of mechanics of novel materials and structures used in aerospace systems. The laboratory is equipped with NI Compact DAQ acquisition system for actuation and sensing applications to understand the mechanics of structures and materials. The laboratory includes an optical microscopy suite to visualize the full-field deformation of nanostructured materials with nanoscale resolution using Digital Image Correlation (DIC). The laboratory also hosts a high speed imaging system to investigate the mechanics of granular media under dynamic loading and the flow of granular media. The laboratory also focusses on the dynamic response of granular media and inhomogeneous materials using a gas-gun based impact testing setup. The laboratory is equipped with a Laser Scanning Doppler Vibrometer system to measure the velocity of vibrations in structures like particle dampers and ferroelectrics in low and high frequency ranges.

Laboratory for Intelligent Systems and Control

HL312 (Demetriou)

The (Laboratory for Intelligent Systems and Control) is a 400 sq. ft. facility equipped for experiments in control of unmanned aerial vehicles, wheeled robots, submersible vehicles, spacecraft, and dynamical systems with flexible structures. Workbenches equipped with power supplies, amplifiers, signal generators, data acquisition systems, and oscilloscopes are provided. For experiments in vehicle autonomy, state-of-the-art microcontroller platforms, such as the Raspberry Pi 2, along with sundry electronic components are available for rapid prototyping and implementation of onboard vehicle control systems. A network of off-the-shelf radio-controlled vehicle platforms such as the IRIS quadrotor helicopters are available. A network of wirelessly-controlled autonomous mobile robots such as the Clearpath Husky A200 UGV with onboard computer, IMU, and Velodyne LIDAR, the TurtleBot with LIDAR, and the iRobot Create wheeled robots are available. For experiments in control and optimization of flexible structures, an active vibration isolation table, velocity sensors, accelerometers, piezoceramic patches for actuation and sensing and a dSPACE® ACE1103 real-time data acquisition and control package are available.

Autonomy, Controls, and Estimation Laboratory

HL311b (Cowlagi)

The Autonomy, Controls, and Estimation (ACE) Laboratory is a 400 sq. ft. facility equipped for experiments related to motion planning and control of autonomous mobile vehicles in unknown or uncertain environments. The lab is home to a portable Vicon motion capture system consisting of 8 Vicon Vero 2.2 cameras with heavy duty tripod mounts. The motion capture system provides localization with a 1mm accuracy. The lab also provides other highly portable localization systems: a Pozyx wifi-based system and a Polhemus radio-based system. Workbenches equipped with power supplies, amplifiers, signal generators, data acquisition systems, and oscilloscopes are available. Several microcontroller platforms such as the Nvidia Jetson and Jetson Nano, aerial vehicle autopilot and remote control hardware, and sundry electronic components are available for rapid prototyping and implementation of onboard vehicle control systems. A multitude of off-the-shelf radio-controlled aerial vehicle and wheeled robotic vehicle platforms are available.

Aerospace Engineering Discovery Classroom

HL216 (AE Faculty)

In the Discovery Classroom, the traditional lecture hall is redefined to combine a multi-media classroom and an adjoining experimental 570 sq. ft. laboratory. The capabilities of the classroom allow us to use an integrated analytical – numerical – experimental approach to aerospace engineering in fludis, propulsion, materials and structures courses. We have designated the approach using this facility as the DIANE philosophy: Daily Integration of Analytical, Numerical, and Experimental methods into aerospace engineering classes. In a typical application, experimental apparatus are demonstrated directly in class during an engineering lecture. Real-time quantitative data are acquired from the apparatus, and the data are analyzed and compared to concurrently developed theory by the students in class. The lab includes a portable wind tunnel, a portable water tunnel, a buckling apparatus, a shear center apparatus and various other setups.

AE Curricular Areas and Courses

The AE degrees are based on coursework shown in Table 1 and research as shown in Table 2. There are five curricular areas of study: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures; General Aerospace Engineering Topics.

Table 1: AE Curricular Areas and Courses

Fluid Dynamics

Item #	Title	Credits
AE 5131	Incompressible Fluid Dynamics	2
AE 5132	Compressible Fluid Dynamics	2
AE 5133	Kinetic Theory of Gases and Applications	2
AE 5134	Plasma Dynamics	2

Propulsion and Energy

Item #	Title	Credits
AE 5231	Air Breathing Propulsion	2
AE 5232	Spacecraft Propulsion	2
AE 5233	Combustion	2
AE 5234	Sustainable Energy Systems	2

Flight Dynamics and Control

Item #	Title	Credits
AE 5331	Linear Control Systems	2
AE 5332	Nonlinear Control Systems	2
AE 5333	Optimal Control for Aerospace Applications	2
AE 5334	Spacecraft Dynamics and Control	2
AE 5335	Autonomous Aerial Vehicles	2

Materials and Structures

Item #	Title	Credits
AE 5431	Solid Mechanics for Aerospace Structures	2
AE 5432	Composite Materials	2
AE 5433	Aeroelasticity	2
AE 5434	Computational Solid Mechanics	2
AE 5435	Fracture Mechanics	2

General Aerospace Engineering Topics

Item #	Title	Credits
AE 5031	Applied Computational Methods for Partial Differential Equations	2
AE 5032	Aerospace Engineering Seminar	0

Table 2: AE Research Courses

Item #	Title	Credits
AE 5098	Directed Research	0
AE 5900	Graduate Internship Experience	
AE 6900	Graduate Internship Experience	
AE 6098	Pre-Dissertation Research	0
AE 6099	Dissertation Research	0

B.S./M.S. in Aerospace Engineering

The combined B.S./M.S. program in Aerospace Engineering is available for currently enrolled WPI Aerospace Engineering majors. Students in the program may complete the B.S. and the M.S degree in Aerospace Engineering in approximately five years of study. When applying to the B.S./M.S. program, students must specify their intention to pursue either the thesis or the non-thesis option. Both options require the completion of 30 graduate credit hours. Students in the thesis option must complete 8 credits of thesis research (AE 5099), whereas students in the non-thesis option may complete up to 8 credits of directed research (AE 5098). Petitions to transfer from/to the non-thesis to/from the thesis option will be considered by the graduate committee. The M.S. degree requires the completion of 30 graduate credit hours.

M.S. in Aerospace Engineering Degree with Thesis Option

Students interested in research with a focus in a specific area are encouraged to select the M.S. AE degree with thesis option which requires a minimum of 8 graduate credit hours in AE 5099 MS Thesis. Students must select a thesis advisor from the AED faculty prior to registration in AE 5099. The thesis advisor also serves as the academic advisor of the student. The thesis submission follows WPI's rules.

The distribution of credits for the M.S. in AE degree with the thesis option is as follows:

- 20 graduate credits in Aerospace Engineering
    - A minimum of 2 graduate credits in each of the five AE Curricular Areas: Fluid Dynamics;

    - Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures; General Aerospace Engineering Topics
    - A minimum of 8 graduate credits in MS Thesis AE 5099
    - 0 graduate credits for four terms in Aerospace Engineering Seminar (AE 5032)
- 10 graduate credits in electives
    - 8 graduate credits in free electives inside or outside AE
    - 2 graduate credits in applied mathematics (MA 501, MA 511, or any other course with the prior approval of the AE graduate committee)

TOTAL 30 Credits

M.S. in Aerospace Engineering Degree with Non-Thesis Option

The Master of Science degree requires the completion of 30 graduate credit hours. The distribution of credits is as follows:

- 20 graduate credits in Aerospace Engineering
    - A minimum of 2 graduate credits in each of the five AE Curricular Areas: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures ; General Aerospace Engineering Topics
    - A maximum of 8 graduate credits in AE Research, of which up to 3 may be in Graduate Internship Experience (AE 5900) and the remaining in Directed Research (AE 5098)
    - 0 graduate credits for four terms in Aerospace Engineering Seminar (AE 5032)
- 10 graduate credits in electives
    - 8 graduate credits in free electives inside or outside AE
    - 2 graduate credits in applied mathematics (MA 501, MA 511 or any other course with the prior approval of AE graduate committee)

TOTAL 30 Credits

Prior to registering for directed research AE 5098, the student must have completed at least 6 graduate credits in AE courses.

For students admitted in the B.S./M.S. program, a maximum of 8 graduate credits may be double counted toward both the undergraduate and graduate degrees. Double counted graduate credits must be in courses, including graduate-level independent study and special topics. A maximum of four 4 out of the 8 credits can be double-counted in 4000-level courses from Engineering, Basic Science or Mathematics. A grade of B or better is required for any course to be double counted toward both degrees.

Acceptance into the B.S./M.S. program signifies approval of the graduate courses listed for credit toward both the undergraduate and graduate degrees.

Type: B.S./M.S.

M.S. in Aerospace Engineering

M.S. in Aerospace Engineering Degree

When applying to the Master of Science in Aerospace Engineering degree, students must specify their intention to pursue either the thesis or the non-thesis option. Both options require the completion of 30 graduate credit hours. Students in the thesis option must complete 8 credits of thesis research (AE 5099), whereas students in the non-thesis option may complete up to 8 credits of directed research (AE 5098). Petitions to transfer from/to the non-thesis to/from the thesis option will be considered by the graduate committee.

Degree Requirements

The AE degrees are based on coursework and Research as shown below. There are five curricular areas of study: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures; General Engineering Topics.

M.S. in Aerospace Engineering Degree with Thesis Option

Students interested in research with a focus in a specific area are encouraged to select the M.S. AE degree with thesis option which requires a minimum of 8 graduate credit hours in AE 5099 MS Thesis. Students must select a thesis advisor from the AED faculty prior to registration in AE 5099. The thesis advisor also serves as the academic advisor of the student. The thesis submission follows WPI's rules.

The distribution of credits for the M.S. in AE degree with the thesis option is as follows:

- 20 graduate credits in Aerospace Engineering
    - A minimum of 2 graduate credits in each of the five AE Curricular Areas: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures; General Aerospace Engineering Topics

    - A minimum of 8 graduate credits in MS Thesis AE 5099
    - 0 graduate credits for four terms in Aerospace Engineering Seminar (AE 5032)
- 10 graduate credits in electives
    - 8 graduate credits in free electives inside or outside AE
    - 2 graduate credits in applied mathematics (MA 501, MA 511, or any other course with the prior approval of the AE graduate committee)

TOTAL 30 Credits

M.S. in Aerospace Engineering Degree with Non-Thesis Option

The Master of Science degree requires the completion of 30 graduate credit hours. The distribution of credits is as follows:

- 20 graduate credits in Aerospace Engineering
    - A minimum of 2 graduate credits in each of the five AE Curricular Areas: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; Materials and Structures ; General Aerospace Engineering Topics
    - A maximum of 8 graduate credits in AE Research, of which up to 3 may be in Graduate Internship Experience (AE 5900) and the remaining in Directed Research (AE 5098)
    - 0 graduate credits for four terms in Aerospace Engineering Seminar (AE 5032)
- 10 graduate credits in electives
    - 8 graduate credits in free electives inside or outside AE
    - 2 graduate credits in applied mathematics (MA 501, MA 511 or any other course with the prior approval of AE graduate committee)

TOTAL 30 Credits

Prior to registering for directed research AE 5098, the student must have completed at least 6 graduate credits in AE courses.

Academic Advising

The schedule of academic advising ensures that students are well advised throughout the program.

Temporary Advisor: upon admission to the M.S. program each student is assigned or may select a Temporary Advisor. Arranges an academic plan covering the first 8 credits of prior to the first registration.

Academic Advisor: elected by a student prior to registering for more than 8 credits. Arranges an academic plan covering the remaining course of study.

AE Curricular Areas and Courses

Type: Master of Science

Ph.D. in Aerospace Engineering

Students admitted to the Ph.D. program in Aerospace Engineering must retain a full-time status by registering for a minimum of 8 credits per semester or a part-time status by registering for a minimum of 4 credits per semester, until they reach the maximum number of credits required by the program. Failure by a student to maintain full-time status or part-time status for one semester will be considered insufficient progress and may result in the removal of the student from the Ph.D. program. Any student pursuing the Ph.D. must establish residency by being in full-time status for at least one continuous academic year.

The course of study leading to the Ph.D. degree in aerospace engineering requires the completion of 90 credits beyond the bachelor's degree, or 60 credits beyond the master's degree.

For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

30 graduate credits in courses

- 18 graduate credits in AE courses (incl. Special Topics, ISP and Graduate Internship Experience)
- 8 graduate credits in courses in or outside of AE
- 2 graduate credits in applied mathematics (MA 501, MA 511 or any other course with the approval of AE graduate committee)
- 2 graduate credits in computational methods (AE 5031, or any other course with the approval of the AE graduate committee)

30 graduate credits in Dissertation Research (AE 6099)

30 graduate credits in

- Additional coursework
- Additional Dissertation Research (AE 6099)
- Supplemental Research (AE 5098, AE 6098)

0 graduate credits for 1 term in AE 6999 Ph.D. Qualifying Examination

0 graduate credits for all terms during residency in AE 5032 Aerospace Engineering Colloquium

TOTAL 90 credits

For students proceeding from Master's to Ph.D. degree, the 60 credits should be distributed as follows:

- 12 graduate credits in AE courses (incl. Special Topics, ISP and Graduate Internship Experience)
- 30 graduate credits in Dissertation Research (AE 6099)
- 18 graduate credits in
  - courses in or outside of AE
  - Dissertation Research (AE 6099)
  - Supplemental Research (AE 5098, AE 6098)
- 0 graduate credits for 1 term during residency in AE 6999 Ph.D. Qualifying Examination
- 0 graduate credits for all terms during residency in AE 5032 Aerospace Engineering Seminar

TOTAL 60 credits

Prior to admission to Candidacy, a student may receive up to 18 credits of pre-dissertation research under AE 6098. Only after admission to Candidacy with the successful passing of AE 6999 may a student receive credit toward Dissertation Research under AE 6099. The result of the dissertation research must be a completed doctoral dissertation.

Academic Advising and Schedule

Temporary Advisor

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 8-10 credits of study. This plan should be arranged before the first day of registration.

Dissertation Advisor and Plan of Study

A student selects an AE Dissertation Advisor who agrees upon prior to registering for more than 8-10 credits. The Dissertation Advisor will approve the Plan of Study which includes the Dissertation Topic.

Ph.D. Qualifying Exam and Admission to Candidacy

Admission to Candidacy will be granted when the student has satisfactorily passed the Ph.D. Qualifying Examination (AE 6999). The Qualifying Examination is intended to measure each student's fundamental knowledge in two Curricular Areas to be chosen by the student from the following: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; and Materials and Structures. The AE 6999 Ph.D. Qualifying Examination is graded using a Pass/Fail system as determined by a) the results from the written Candidacy Test in the two Curricular Areas chosen by the student and b) the student's performance in graduate courses taken at WPI in the same two Curricular Areas.

The written Candidacy Test is typically offered during the first week of B and/or D term. A student will be tested on material from two (2) graduate courses of their choice in one AE Curricular Area and on material from one (1) graduate course of their choice in a second AE Curricular Area. In the term preceding the written Candidacy Test, a student must inform the Graduate Coordinator about their selection of the two Curricular Areas and the three courses. The written Candidacy Test is graded using the Satisfactory/Not Satisfactory Performance (SP/NP) grading system and has no retake.

If a student fails to register or fails to earn a Pass in the AE 6999 Ph.D. Qualifying Examination prior to completion of 18 credits after admission to the Ph.D. program, the student must withdraw from the Ph.D. program by end of the B term or D term of the year registered for the Qualifying Examination.

Dissertation Committee and Dissertation Proposal

Formed prior to registering for more than 18 credits and after Admission to Candidacy. The Dissertation Committee consists of the Dissertation Advisor, at least one core faculty of the Aerospace Engineering Program, and at least one outside member.

Each Doctoral Candidate must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. The Dissertation Proposal must be made within a year after the Qualifying Exam and admission to candidacy. Both the written and oral parts of the Proposals are presented to members of the Dissertation Committee and a representative from the AE Graduate Committee. The prepared portion of the oral presentation should not exceed 40 minutes, and up to 60 minutes should be allowed for discussion. If the members of the Dissertation Committee and the Graduate Committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, then the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 35 minutes allowed for discussion. Students can continue their research only if the Dissertation Proposal is approved. If the Dissertation Proposal is not approved, the Doctoral Candidate may find a new Dissertation Advisor and proceed with a new Dissertation Proposal.

Dissertation Defense

Each Doctoral Candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the Dissertation Committee and a representative of the AE Graduate Committee who is not on the Dissertation Committee. The defense is open to public participation and consists of a one-hour presentation followed by a one-hour open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the aerospace engineering department. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Type: Ph.D.

Bioinformatics and Computational Biology

Faculty with Research Interests

D. Korkin, Professor, Computer Science, and BCB Program Director; Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology, data mining, machine learning.

A. Arnold (Mathematical Sciences); Ph.D., Case Western University, 2014. Mathematical biology, Bayesian inference, parameter estimation in biological systems.

L. Harrison, AssociateProfessor, Computer Science; Ph.D., UNC-Charlotte, 2013. Information visualization, visual analytics, human-computer interaction.

A. Manning, Assistant Professor, Biology and Biotechnology; Ph.D., Geisel School of Medicine at Dartmouth University, 2008. Cancer Cell Biology, cell cycle regulation, mitotic progression and chromosome segregation, chromatin regulation, and genome stability.

S. D. Olson, Professor, Mathematical Sciences; Ph.D. North Carolina State University, 2008. Mathematical biology, chemical signaling, mechanics, and hydrodynamics.

R. Paffenroth, Professor, Mathematical Sciences; Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.

R. Prusty Rao, Professor, Biology and Biotechnology; Ph.D., Penn State University-Medical School. Genomic studies and high throughput screening to understand and manage fungal diseases in humans.

C. Ruiz, Professor, Computer Science; Ph.D., University of Maryland, 1996. Data mining, machine learning, artificial intelligence, biomedical data mining.

E. F. Ryder, Associate Professor, Biology and Biotechnology, and BCB Program Associate Director; Ph.D., Harvard University, 1993. Computational biology, simulation of biological systems.

B. Servatius, Professor, Mathematical Sciences; Ph.D., Syracuse University, 1987. Combinatorics, matroid and graph theory, structural topology, geometry, history and philosophy of mathematics.

S. Shell, Associate Professor, Biology and Biotechnology; Ph.D., University of California San Diego. Bacterial pathogenesis, bacterial stress response, prokaryotic gene regulation, prokaryotic genomics and transcriptomics.

L. Vidali, Associate Professor, Biology and Biotechnology; Ph.D., University of Massachusetts-Amherst. Plant cell biology and molecular genetics, live cell microscopy, molecular motors/cytoskeleton.

M. Wu, Assistant Professor, (Mathematical Sciences); Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.

Z. Wu, Professor of Mathematical Sciences, Ph.D., Yale, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.

E. M. Young, Assistant Professor, Chemical Engineering; Ph.D., University of Texas at Austin. Synthetic biology, metabolic pathway engineering, yeast gene expression, transport protein engineering.

J. Zou, Associate Professor; Ph.D., University of Connecticut, 2009. Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Affiliated Faculty with Research Interests

E.O. Agu, (Computer Science); Ph.D., University of Massachusetts-Amherst, 2001. Computer graphics, mobile computing, wireless networks, use of smartphones as a platform to deliver better healthcare.

T. Dominko, (Biology and Biotechnology); D.V.M, Ph.D., University of Wisconsin-Madison. Regenerative cell biology, stem cells, role of oxygen and FGF2 in nuclear reprogramming, epigenetics, reproductive/developmental biology.

J. P. Duffy, (Biology and Biotechnology); Ph.D., University of Texas. Signal transduction dynamics and modeling, computational identification of intracellular protein motifs.

M. Eltabakh, (Computer Science); Ph.D., Purdue University, 2010. Database management systems, information management.

A. Mattson, (Chemistry and Biochemistry), Ph.D. Northwestern University: drug design, molecular modeling.

E. A. Rundensteiner, (Computer Science); Ph.D., University of California, Irvine, 1992. Data and information management, big data analytics, visual data discovery, stream and pattern mining, large scale data infrastructures.

E. T. Solovey, Assistant Professor; Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.

J. Srinivasan, (Biology and Biotechnology); Ph.D., University of Tuebingen, Germany. Genetics, behavioral neuroscience, molecular neurobiology, chemical biology, evolutionary ecology.

D. Tang, (Mathematical Sciences); Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.

S. Walcott, (Mathematical Science); Ph.D., Cornell University, 2006. Systems biology, molecular modeling, mathematical biology.

A. Yousefi, (Computer Science). PhD., University of Southern California: computational neuroscience, neurostatistics.

Programs of Study

The Bioinformatics and Computational Biology (BCB) Program offers graduate studies toward the B.S./M.S., M.S., and Ph.D. degrees. With the advent of large amounts of biological data stemming from research efforts such as the Human Genome Project, there is a great need for professionals working at the interface of biology, computer science, and mathematics. A truly interdisciplinary program, the BCB degree requires advanced course work in all three of these areas. Our faculty and strong relationships with the University of Massachusetts Medical School provide students with the resources to perform innovative scientific research at the highest level.

The diverse learning environment that characterizes our program promotes easy exchange of ideas, access to all the necessary resources, and encourages creative solutions to pressing scientific questions.

Admissions Requirements

Students applying to the M.S. or Ph.D. Degree Programs in Bioinformatics and Computational Biology (BCB) are expected to have a bachelor's degree in either biology, computer science, mathematics, or a related field, and to have taken introductory courses in each of the three disciplines: biology, computer science, and mathematics. For example, a student with a bachelor's degree in biology is expected to have also completed courses in programming, data structures, calculus, and statistics prior to submitting an application. A strong applicant who is missing background in one of the three areas may be provisionally admitted, with the expectation that he or she will take and pass one or more undergraduate courses in the area of deficiency either during the summer prior to admission or within the first semester after admission. The determination of what course or courses will satisfy this provision will be made by the Program Review Committee.

Certificate Requirements

A certificate program in BCB is not offered at present.

Facilities/Research Labs/ Research Centers

The BCB Program is supported by a wide assortment of resources within the participating departments, WPI Computing and Communication Center (CCC), and the research laboratories at Gateway Park and UMMS. Grid and cloud computing, along with high-speed networking, provides exceptional computational infrastructure. Access to most major biological databases is available to students and researchers, and a wide range of bioinformatics software packages are installed and maintained. Wet labs at Gateway Park and UMMS are available by permission of BCB faculty members and affiliates.

B.S./M.S. in Bioinformatics and Computational Biology

Students enrolled in the B.S./M.S. program must satisfy all the program requirements of the B.S. degree and all the program requirements of the M.S. degree as described at the URL below. They may double-count 4000-level or graduate courses whose credit hours total no more than 40% of the 33 credit hours required for the M.S. degree, and that meet all other requirements for each degree, towards both their undergraduate and graduate degrees. Students must register for B.S./M.S. credit prior to taking the courses, as faculty may assign extra work for those taking the course as part of both degrees. In consultation with the academic advisor, the student must prepare a Plan of Study outlining the selections that the student will make to satisfy the B.S./M.S. degree requirements, including the courses that the student will double count. This Plan of Study must then be approved by the Program Review Committee. Students must consult their advisors and the graduate catalog, as individual departments may have restrictions on which undergraduate courses might be taken for graduate credit, and on which pairs of undergraduate and graduate courses cannot both be taken for credit.

Type: B.S./M.S.

M.S. in Bioinformatics and Computational Biology

Students pursuing the M.S. degree in Bioinformatics and Computational Biology must complete a minimum of 33 credits of relevant work at the graduate level. These 33 credits must satisfy the 6-9 credit M.S. thesis or internship requirement, and the 24-27 credit coursework requirement described in detail at the URL below. Coursework requirements include competency in each of the areas of biology, computer science, mathematics, and interdisciplinary studies in bioinformatics / computational biology, as well as more advanced courses and an ethics course. The M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, students who are pursuing a combined B.S./M.S. degree, and students who are pursuing a combined M.S. / Ph.D. degree. Courses and research projects taken at nearby University of Massachusetts Medical School (UMMS) may be applied to this degree. Upon acceptance to the M.S. program, students will be assigned an academic advisor. In consultation with the academic advisor, the student must prepare a Plan of Study outlining the selections that the student will make to satisfy the M.S. degree requirements. This Plan of Study must then be approved by the Program Review Committee, which consists of faculty members from each of the three participating WPI departments.

Type: Master of Science

Ph.D. in Bioinformatics and Computational Biology

Students pursuing the doctoral degree in BCB must complete a minimum of 90 graduate credits of relevant work beyond the bachelor's degree (60 credits if the student possesses a relevant M.S. degree). At least 30 credits must be in dissertation research. Coursework requirements are similar to those for the M.S. degree, with an additional required course in proposal writing. For Ph.D. candidates, presentation of research work is required each year, and there is a teaching / mentorship requirement as well. Students may pursue up to 6 graduate credits as an internship with an external sponsor. Detailed requirements are found at the URL below. Upon acceptance to the program, students will be assigned a temporary academic advisor and prepare a Plan of Study similar to the procedure for M.S. students. Ph.D. students are required to complete rotations with at least two program faculty members in the first year of the program before choosing a research advisor; choosing co-advisors in different disciplines is strongly encouraged. Students are encouraged to consider UMMS faculty for rotations and as co-advisors, and may take UMMS courses to fulfill course requirements.

Qualifying Exam and Dissertation Defense

The Qualifying Examination will be comprised of researching, writing, and defending a research proposal. The student is required to successfully complete the Qualifying Examination no later than the first semester of his/her third year in the program. If the Qualifying Examination is successfully completed, the proposed work may constitute the basis of the student's dissertation research. All Ph.D. students must produce and orally defend a dissertation. The research must constitute a contribution to knowledge in the field of Bioinformatics and Computational Biology and must be of publication quality. Students must defend the dissertation orally in a public presentation, followed by a private defense.

Type: Ph.D.

Biology and Biotechnology

Faculty

R. P. Rao, Professor and Department Head; Ph.D., Penn State University-Medical School; M.S (Dual), Drexel University; emerging Infectious diseases, virulence and host defense mechanisms.

T. Dominko, Professor; D.V.M., Ph.D., University of Wisconsin-Madison; investigation of the molecular basis of stem cell gene activation and induced pluripotency.

J. B. Duffy, Associate Professor; Ph.D., University of Texas; defining signaling pathways that program cellular diversity.

J. A. King, Professor and Peterson Family Dean of Arts and Sciences; Ph.D., New York University; M.S, City University of New York; neuronal plasticity associated with neurological and psychiatric disorders utilizing functional magnetic resonance imaging, molecular biology and behavior.

A. L. Manning, Assistant Professor; Ph.D., Dartmouth University-Geisel School of Medicine; cancel biology, cell cycle regulation, mitotic progression and chromosome segregation, chromatin regulation, and genome stability.

L. M. Mathews, Associate Professor; Ph.D., University of Louisiana; aquatic ecology, plant-insect coevolution, design and application of molecular genetic tools for ecological research, conservation biology.

I. Nechipurenko, Assistant Professor; Ph.D., Case Western Reserve University, School of Medicine; developmental neurobiology, genetics, cilia assembly and signaling in neurons.

K. K. Oates, Professor; Ph.D., The George Washington University Biochemistry; thymic hormone characterization, monoclonal antibody production, immunology of disease, undergraduate STEM education, STEM Education for Development.

J. Rulfs, Associate Professor; Ph.D., Tufts University; cell culture model systems of signal transduction, metabolic effects of phytoestrogens, cultured cells in tissue engineering.

E. F. Ryder, Associate Professor; Ph.D., Harvard University; M.S., Harvard School of Public Health; bioinformatics and computational approaches to understanding biological systems.

S. S. Shell, Assistant Professor; Ph.D., University of California San Diego; understanding how gene regulation controls stress responses and antibiotic sensitivity in mycobacteria.

J. Srinivasan, Associate Professor; Ph.D., University of Tuebingen, Germany; neural networks underlying social behaviors,role of olfactory dysfunction in neurodegenerative disorders, optogenetics & engineering of neural networks.

L. Vidali, Associate Professor; Ph.D., University of Massachusetts-Amherst; understanding the molecular and cellular mechanisms underlying the role of the cytoskeleton in plant cell organization and growth.

P. J. Weathers, Professor; Ph.D., Michigan State University; investigation of Artemisia annua antimalarial, antimicrobial drug production in planta, and bioavailability and therapeutic efficacy in vitro and in vivo.

Research Interests

Enabled by a world-class research infrastructure, students explore their passion for discovery while driving cutting-edge, hypothesis-driven research alongside our diverse and dynamic faculty body. Faculty areas of expertise in which students may engage in directed student include:

- Cancer cell biology
- Cognition and behavior
- Cytoskeletal dynamics
- Drug resistance
- Epigenetics and gene regulation
- Infectious diseases
- Neurobiology
- Regenerative medicine
- Signal transduction mechanisms

The department strongly recommends that, prior to applying, prospective students review the information on the department's website to identify potential research interests and faculty advisors.

Molecular and Cellular Biology and Biotechnology

Areas of focus: Cytoskeletal dynamics, epigenetics/gene regulation, and signal transduction mechanisms
Biological systems: C. elegans, Drosophila, M. musculus,

Physcomitrella, and C. albicans, S. cerevisae, Cultured cells
Faculty: Tanja Dominko, Joe Duffy, Amity Manning, Lauren Mathews, Inna Nechipurenko, Reeta Rao, Jill Rulfs, Liz Ryder, Scarlet Shell, Jagan Srinivasan and Luis Vidali.

Development, Neurobiology, and Organismal Biology and Biotechnology

Areas of focus: Cancer biology, regenerative medicine, neuronal migration, circuits, and degeneration, pathogenic mechanisms, and plant biology
Model systems: C. elegans, Drosophila, M. musculus, Physcomitrella, and C. albicans, Cultured cells
Faculty: Tanja Dominko, Joe Duffy, Amity Manning, Inna Nechipurenko, Reeta Rao, Liz Ryder, Scarlet Shell, Jagan Srinivasan, and Luis Vidali.

Behavioral and Environmental Biology and Biotechnology

Areas of focus: Animal behavior, biological diversity, brain plasticity, pollinator ecology, and plant biology
Model systems: Danaus plexippus, Orconectes spp., and Drosophila
Faculty: Joe Duffy, Lauren Mathews, Jagan Srinivasan and Pam Weathers.

Programs of Study

With the advent of genomics, the 21st Century has been termed a "revolutionary" era in Biology and Biotechnology. The Department of Biology and Biotechnology (BB) is perfectly situated for this transition with the construction of the Interdisciplinary Life Sciences and Bioengineering Center at Gateway Park. This state-of-the-art building integrates Life Sciences and Bioengineering at WPI in addition to housing a number of technology centers and biotechnology start-ups.

The Department offers a fulltime research-oriented program for incoming graduate students, leading to either a doctor of philosophy (Ph.D.) in Biology and Biotechnology or Masters (M.S.) degree in Biology and Biotechnology. These programs require students to successfully complete a set of required courses in the field and a thesis project or dissertation that applies the basic principles of biology and biotechnology using hypothesis driven experimental methods to address a specific research problem.
In addition, the department also offers a skills-based non-thesis MS degree in Biotechnology, delivered in a blended format. The non-thesis M.S. program is designed to provide a broad base in advanced coursework and laboratory training in techniques that are applicable to the Biotechnology industry.

Graduates will have a broad knowledge of the field of biology and biotechnology, a detailed knowledge in their area of specialization, a working knowledge of modern research tools, a strong appreciation for scientific research in theoretical and experimental areas, and a foundation for lifelong learning and experimenting, both individually and as part of a team. Students who complete these programs will be well prepared for careers in the academics and private sectors or further graduate education.

Application and Admission

Applications should be made to the specific degree programs. The department accepts applications for admission to the M.S. or Ph.D. in biology and biotechnology programs in the Fall semester only. M.S. in Biotechnology applications are reviewed on a rolling basis.

Admission Requirements

See admission information.

Research Facilities and Centers

Life Sciences and Bioengineering Center (LSBC)

Located in Gateway Park, the world-class, 124,600-square-foot LSBC was built in 2007 and serves as the school's focal point for graduate education and research in the life sciences and related bioengineering fields. It's also home to life sciences companies, state-of-the-art core facilities, and WPI's Corporate and Professional Education division.

The Core facilities include an Imaging core providing a wide range of imaging capabilities for live and fixed samples including Confocal microscopy with FRET and FRAP, Atomic Force Microscopy, and microinjection/manipulation and histology capabilities; an Analytical core, with NMR, Atomic-absorption (AA) spectroscopy, LC-MS and GC-MS capabilities; and Molecular Cores for DNA/RNA/tissue work. Additional shared common spaces include centralized facilities for waste disposal, media preparation as well as dishwashing. The facility is part of the WPI-University of Massachusetts Consortium which allows researchers at both institutions to access facilities and services at the other institution at "in-house" rates.

Bioprocess Center (BPC)

Researchers at the BPC design and develop scalable processes for drug manufacturing. The BPC contracts with biotechnology companies, to supply drug targets in research quantities and conduct lab- and pilot-scale process development.

Biomanufacturing Education and Training Center (BETC)

WPI's Biomanufacturing Education and Training Center, the first of its kind in the Northeast, provides innovative workforce development solutions customized to the specific needs of an industry. Serving life sciences companies from across the region and the globe, the center represents an innovative partnership of academia and industry by offering hands-on and classroom training by experts in a wide-range of roles and disciplines.

Certificate in Biomanufacturing

The Graduate Certificate in Biomanufacturing must be composed of 12 credits of graduate coursework chosen from a list provided in the graduate catalog and approved by the BBT graduate coordinator:

Type: Certificate

Three Skills-Based Courses (9 credits)

Courses include:

Item #	Title	Credits
BB 505	Fermentation Biology	3
BB 508	Animal Cell Culture	0
BB 509	Scale Up of Bioprocessing	3
BB 560	Methods of Protein Purification and Downstream Processing	3
BB 581/BCB 501	Bioinformatics	3

One, thematically related, graduate level course (3 credits)

Courses include:

Item #	Title	Credits
BB 551	Research Integrity in the Sciences	1
BB 590	Capstone Experience in Biology and Biotechnology	0
BB 561	Model Systems: Experimental Approaches and Applications	2
BB 562	Cell Cycle Regulation	3
BCB 502/CS 582	Biovisualization	3
CH 540	Regulation of Gene Expression	2
CHE 521	Biochemical Engineering	3

M.S. in Biology and Biotechnology (thesis-based)

Students pursuing the M.S. degree in Biology and Biotechnology must successfully complete a minimum of 30 credit hours of course and thesis work per the distribution requirement below. All courses must be at the 500 or 4000 level and no more than 9 credits may be at the 4000 level. An approved list is provided in the department's graduate handbook.

Students must assemble an Advisory Committee of three or more faculty members of which a majority must be Biology and Biotechnology program faculty members. The Advisory Committee must review and approve each M.S. student's program of study and thesis research. Students must successfully complete a thesis including a written thesis and oral defense.

Type: Master of Science

Credit Requirement

Item #	Title	Credits
	Course work at the 500 or 4000 level	15
	Thesis Research	15

Course Requirement

Item #	Title	Credits
BB 554	Journal Club	1
BB 551	Research Integrity in the Sciences	1
BB 501	Seminar	1
	BB Course(s)	3
	Electives (approved by Advisory Committee)	6
BB 599	Master's Thesis	0

M.S. in Biotechnology (skills-based)

Students pursuing skills-based M.S. degree in Biotechnology must complete a minimum of 30 credit hours beyond the bachelor's degree. Students enrolled in the M.S. in Biotechnology program must successfully complete 15 credit hours of BB courses, 9 credit hours of skills-based courses, chosen from an approved list provided below and 6 credit hours of elective courses. All courses must be at the 500 or 4000 level and no more than 9 credits may be at the 4000 level. An approved list is provided below. Additional courses will require approval of graduate co-ordinator.

Type: Master of Science

Credit Requirement

Item #	Title	Credits
	Course work at the 500 or 4000 level	15
	Electives (approved by Advisory Committee)	6
	Skills Based Courses	

Ph.D. in Biology and Biotechnology

In addition to the WPI requirements, a dissertation (minimum of 30 credit hours) and dissertation defense is required of all Ph.D. students. It is the intention of the faculty that doctoral students develop skills not only in their research area, but also receive training in interdisciplinary approaches to research, presentation skills (oral and written), pedagogical approaches, experimental design, and professional ethics within the life sciences. Specific operational details of the program, including the qualifying exam and dissertation defense, can be found in the Biology and Biotechnology graduate handbook.

Publications

All successful Ph.D. students are expected to have at least one author-manuscript published or accepted for publication in a peer-reviewed journal. In addition, the students are required to present their thesis work at a national or international conference.

Qualifying Exam, Reports and Dissertation Defense

A Ph.D. qualifying exam is required and should be taken towards the end of the second year of study. A majority of the Examining Committee must be members of the Biology and Biotechnology department faculty. The committee must also approve the student's dissertation research proposal and review student's progress through committee meetings. Candidates for the Ph.D. degree must give annual presentations of their research work to the department as part of the graduate seminar course. A public defense of the completed dissertation is required of all students and will be followed immediately by a defense before the Examining Committee. All members of the Examining Committee must be present for the defense.

Type: Ph.D.

Biomedical Engineering

Faculty

K. L. Billiar, Professor and Department Head; Ph.D., University of Pennsylvania; Biomechanics of soft tissues and biomaterials, mechanobiology, wound healing, tissue growth and development; functional tissue engineering, regenerative medicine.

D. R. Albrecht, Associate Professor; Ph.D., University of California, San Diego; bioMEMS, microfluidics, quantitative systems analysis and modeling, biodynamics, neural circuits and behavior, optogenetics, high-throughput chemical/genetic screens, tissue engineering, 3-D cell micropatterning, dielectrophoresis.

J. Coburn, Assistant Professor; Ph.D., Johns Hopkins University; biomaterials, scaffolds, tissue engineering, 3-D tissue models, stem cells, cell-matrix/material interactions, drug delivery, oncology therapeutics.

S. Ji, Professor; D.Sc., Washington University in St. Louis; Biomechanics, brain injury, finite element analysis, multi-scale modeling, neuroimaging, medical image analysis, sports medicine.

A.C. Lammert, Assistant Professor; Ph.D., University of Southern California; Neuroengineering, computational modeling, signal processing, sensorimotor control, brain health.

S. Mensah, Assistant Professor; Ph.D., Northeastern University; Pulmonary Vascular Regeneration, Tissue Engineering, Medical Device Development for Global Health

G. D. Pins, Professor; Ph.D., Rutgers University; Cell and tissue engineering, biomaterials, bioMEMS, scaffolds for soft tissue repair, cell-material interactions, wound healing, cell culture technologies.

M. W. Rolle, Professor, Ph.D., University of Washington, Seattle; Cardio-vascular tissue engineering, bioreactor design, cell-based tissue repair, cell and molecular engineering, cell-derived extracellular matrix scaffolds, delivery and control of extracellular matrix genes.

K. L. Troy, Professor; Ph.D., University of Iowa; orthopedic biomechanics, multi-scale modeling, finite element analysis, medical image analysis, bone and joint structure.

C. F. Whittington, Assistant Professor; Ph.D., Purdue University; Cell-extracellular matrix interactions, biomaterials, 3D culture, tissue engineering, mechanobiology, disease models, tumor microenvironment, tumor metastasis, phenotypic assay development, high-throughput and high-content screening.

H. Zhang, Assistant Professor; Ph.D., Johns Hopkins University; Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Research Interests

Biomedical engineering (BME) faculty and graduate students work in multi-disciplinary teams across campus, as well as with external collaborators in academia, medicine and industry. Biomedical engineering graduate students may conduct thesis and dissertation research and projects under the supervision of primary BME department faculty or collaborative BME faculty advisors. Please refer to the Biomedical Engineering Department website for a current listing of primary and collaborative faculty (www.wpi.edu/+bme) and their research interests. Primary areas of research focus include:

Biomaterials and Tissue Engineering

Several BME researchers at WPI focus on creating biomaterials and engineered tissues for regenerative medicine and drug discovery applications. Research projects include: engineered biomaterials for cell delivery and tissue repair (cardiac patches and skeletal muscle regeneration), microtissue models of normal and diseased human tissues (liver, cardiovascular, skeletal muscle and cancer), advanced biomanufacturing of cells, biomolecules, biomaterials, and tissue biofabrication. More recent interdisciplinary work focuses on the use of decellularized plant tissues as biomaterials, and exploring the plant-animal cell interface for the development of advanced biomanufacturing and tissue engineering processes.

Primary faculty: Billiar, Coburn, Pins, Rolle, Whittington

Collaborative faculty: Camesano, Dominko, Roberts, Soboyejo, Weathers

Biomechanics and Mechanobiology

Biomechanics research at WPI focuses on measuring the effects of mechanical forces on skeletal and soft tissue remodeling, and using imaging data and computational tools to understand these effects in the context of human organ and tissue function. Projects include quantifying the effects of exercise and pathology (aging, injury and non-loading, such as in spinal cord injury) on bone remodeling and mechanics, modeling concussion injury in the brain, and applications of robotics in rehabilitative medicine and image-guided surgery. Mechanobiology research aims to understand the mechanical forces through which cells act on and respond to their environment within normal and diseased tissues (heart valve disease, cardiac repair, cancer).

Primary faculty: Billiar, Ji, Troy, Zhang

Collaborative faculty: Fischer, Fofana, Popovic, Tang, Wen

Bioinstrumentation and Signal Processing

Bioinstrumentation research at WPI focuses on developing sensors for physiological monitoring (pulse oximeters, pressure ulcer sensors). Signal processing research extends to the application of quantitative microscopy and machine learning to identify cell phenotypes associated with health and disease (cancer metastasis, quality assessment for cell manufacturing). Quantitative microscopy and imaging, combined with microfabricated MEMS devices for whole organism studies (C. elegans), are being applied to enable high throughput and bioinformatics analysis of neurobiology networks and behavior to model human neurobiology (sleep, autism).

Primary faculty: Albrecht, Lammert

Collaborative faculty: Clancy, Liu

Research Laboratories and Facilities

Biomedical Engineering research laboratories are located in the four-story, 125,000-square-foot **WPI Life Science and Bioengineering Center (LSBC)** at Gateway Park (60 Prescott Street). Laboratory capabilities and equipment include:

Biomaterials fabrication (electrospinning, polymer synthesis, chemical modification, plant- and animal-based biomaterial processing and synthesis)

Biomedical sensors and bioinstrumentation (design and microfabrication of reflective pulse oximetry sensors, microcomputer-based biomedical instrumentation, digital signal processing, wearable wireless biomedical sensors, application of optics to biomedicine and telemedicine)

Cell culture (class I and II biosafety cabinets, incubators, supporting infrastructure)

Histology (paraffin processing and embedding equipment, microtomes, cryotome and special staining stations)

Medical imaging (quantitative computed tomography, robot-guided ultrasound imaging to measure mineralization in bone)

Microfabrication lab (rapid prototyping microfluidic and microelectical mechanical systems (MEMS))

Microscopy (multiple inverted and epifluorescent microscopes, confocal microscopes, atomic force microscopes, light sheet imaging, live still and video image capture of cells, tissues and organisms, fluorescent tracking and quantitative analysis of neural and muscle cell activity)

Mechanical testing (Anton-Paar Rheometer and Optics-11 Nano/micro-indentation; Instron EPS 1000; custom mechanical testing and conditioning systems)

Motion capture and computational mechanics (head impact sensors, gait analysis, high density mapping of soft tissue mechanics, integration of medical imaging data with multi-scale and finite element modeling of musculoskeletal and brain injury biomechanics)

In addition, biomedical engineering faculty and students have access to other WPI facilities and resources at Gateway Park, including courses and equipment housed in the **Biomanufacturing Education and Training Center** (BETC), and courses and events at the **Foisie School of Business**, both located next door to LSBC at 50 Prescott Street. **Robotics Program** research laboratories are located across the street at 85 Prescott Street.

Two new WPI Gateway Park research facilities opened in 2019:

Practice Point is a new facility that houses point-of-care suites where industry-clinician-academic research teams will collaborate to develop advanced healthcare technologies. Research focus areas include medical and surgical robotics, image-guided robotic surgery, assistive technologies, home health care, digital and connected health systems, and advanced prosthetic and rehabilitative engineering.

Advanced Integrated Manufacturing (AIM) Photonics Lab (in partnership with Quinsigamond Community College) enables rapid prototyping, testing, and training in advanced sensing technology to support economic and workforce development and innovation in manufacturing.

AIM is one of the eight national **Manufacturing USA Institutes** of which WPI is a member. This has enabled unique opportunities to engage in industry-government-academic research partnerships that create value for areas of national need in advanced manufacturing. Primary and collaborative BME faculty are active members of the **Advanced Regenerative Medicine Institute (ARMI) and National Institute for Innovation in Manufacturing.**

Boston Seaport

In January 2018, WPI opened the doors to a new space at the heart of Boston's Seaport District, home to a number of innovative technology companies. The facility houses a classroom, conference room, event space, and several meeting spaces that can be reserved by student and faculty teams working with Boston and Cambridge companies, academic or clinical research partners.

Regional Research Partnerships

WPI's geographic location in the heart of central Massachusetts makes it accessible to regional academic and medical centers in Boston and Cambridge, and hundreds of medical device and biotechnology companies, hospitals and research facilities throughout the northeast.

University of Massachusetts Medical School (UMMS) is located in Worcester less than 2 miles from the WPI campus. BME faculty and students engage in many active collaborations with faculty and clinicians at UMMS. With guidance and approval from the BME Graduate Studies Committee, BME graduate students may take courses and pursue research and projects advised by BME program faculty at UMMS.

U.S. Army Natick Soldier Systems Center (NSSC) is located in nearby Natick, Massachusetts. BME faculty and students engage in collaborative projects focused on making soldiers' lives easier, healthier, and safer.

Tufts Cummings School of Veterinary Medicine is located in nearby Grafton, Massachusetts (approximately 8 miles from WPI campus). BME faculty and students engage in research and design projects in collaboration with veterinarians and research faculty at Tufts to improve veterinary medicine.

Programs of Study

The goal of the biomedical engineering (BME) graduate programs is to apply engineering principles and technology that create value and innovative approaches to solve significant biomedical problems. Students trained in these programs have found rewarding careers in major medical and biomedical research centers, academia, medical device and biotechnology industries, and entrepreneurial enterprises.

BME graduate programs are designed to be flexible, student-centered, and customizable to each individual student's academic background, professional experience, and career goals. Courses may be taken on campus or online (as available). Depending on the specific degree program, coursework, thesis and dissertation research, and project work may be integrated with industry co-ops and internships, full-time employment in a related industry, or an international research experience.

Each admitted and matriculated student is assigned a BME Faculty Academic Advisor to provide guidance on course selection and degree program planning. In addition, all students submit an individual Plan of Study to the BME Graduate Studies Committee for review during their first semester, and periodically throughout their degree program, for feedback to ensure that they are on track to meet degree requirements.

All BME graduate degree programs adhere to WPI's general requirements detailed in the WPI Graduate Catalog.

Doctoral Programs

The degree of doctor of philosophy in Biomedical Engineering is conferred on candidates in recognition of exceptional academic achievement and the ability to carry on original independent research. Graduates of the program will be prepared to lead research projects in academic institutions, government agencies, or in the medical device and biotechnology industries.

Master's Degree Programs

There are two master's degree options in biomedical engineering: the course-based Master of Engineering (M.E.), and the Master of Science (M.S.) in Biomedical Engineering. For the M.S. degree, students may choose a Thesis-Based or Project-Based program of study. While the expected levels of student academic performance are the same for all three degree options, they are oriented toward different career goals. The Thesis-Based M.S. is oriented toward the student who wants to focus on a particular facet of biomedical engineering practice or research, or as preparation for pursuing doctoral research. Due to the nature of open-ended independent research, a thesis project may extend beyond the time required to complete the required courses in the Project-Based M.S. or M.E. degree programs. The Project-Based M.S. option is designed to gain hands-on technical experience by engaging in defined engineering design projects relevant to clinical or industry stakeholders. The M.E. option is course-based and designed for the student interested in acquiring advanced technical depth in an area of biomedical engineering specialization, and may be completed on campus or online. The M.S. or M.E. degrees can serve as a terminal degree for students interested in advanced technical training, professional development, and specialization in biomedical engineering.

Combined B.S./Master's Degree Program

This program affords an opportunity for outstanding WPI undergraduate students to earn both a B.S. degree and a master's degree in biomedical engineering concurrently, and in less time than would typically be required to earn each degree separately. The principal advantage of this program is that it allows for certain credits to be counted towards both degree requirements, thereby reducing the total number of courses taken to earn both degrees. With careful planning and motivation, the Combined Program typically allows a student to complete requirements for both degrees with only one additional year of full-time study beyond the B.S. degree (five years total). However, because a student must still satisfy all degree requirements, the actual time spent in the program may be longer than five years.

Students in the Combined Program may choose to complete any one of the master's degree options: a Thesis-Based or Project-Based Master of Science (B.S./M.S.) or a Master of Engineering (B.S./M.E.).

Admissions Requirements

Biomedical engineering embraces the application of engineering to the study of medicine and biology. While the scope of biomedical engineering is broad, applicants are expected to have an undergraduate degree or a strong background in engineering and to achieve basic and advanced knowledge in engineering, life sciences, and biomedical engineering. Applicants with degrees in physical and computational sciences, including physics, computer science and applied mathematics are also encouraged to apply.

Applicants with undergraduate degrees in biology or pharmacy that do not have a strong computational or engineering focus are encouraged to explore advanced degree programs offered by collaborating WPI Life Science and Bioengineering departments, such as Biology and Biotechnology (BBT), Bioinformatics and Computational Biology (BCB) or Chemistry and Biochemistry (CBC).

Master of Engineering in Biomedical Engineering

A minimum of 33 credit hours is required for the Master of Engineering degree. Course requirements include:

- 12 credits of biomedical engineering (any BME course except BME 560, 562, or 564)
- 3 credits of life science (e.g., BME 560, 562, 564; graduate-level biology courses)
- 3 credits of advanced mathematics (e.g., MA 501, 511; graduate-level math courses)
- 3 credits of life science or advanced mathematics
- 12 credits electives
- In addition, students are required to pass BME 591: Graduate Seminar twice.

Electives may include any WPI graduate-level engineering, physics, mathematics, biomedical engineering, or equivalent course, subject to approval of the BME Graduate Studies Committee. Students may substitute 3 to 6 credits of directed research for 3 credits of biomedical engineering and/or 3 credits of electives.

Type: Master of Engineering

M.S. in Biomedical Engineering

A minimum of 30 credit hours is required for the Master of Science degree, which may be met by satisfying the requirements for a Thesis-Based or Project-Based program of study. BME courses include BME 500-level or 4000-level courses (except BME 4300. MQP Capstone Design). Electives may include any WPI graduate-level engineering, physics, math, biomedical engineering, or equivalent course (500- or 4000-level), subject to the approval of the department Graduate Studies Committee. A maximum of 8 credits of coursework at the 4000-level may be applied to meet the requirements for the Master of Science degree.

Type: Master of Science

M.S. (Thesis-Based) 30 Credits

Item #	Title	Credits
	BME Courses	12
BME 599	Master's Thesis	6
	Electives (12 credits)	12

M.S. (Project Based) 30 credits

Item #	Title	Credits
	BME Courses	12
BME 597	BME Professional Project	6
	Electives (12 credits)	12

Thesis (6 credits, Thesis-Based M.S.)

The Thesis-Based M.S. program requires a minimum of 6 credits of **BME 599. Master's Thesis** and completion of an independent research project under the supervision of a Biomedical Engineering Program Faculty advisor. This option is well-suited for the student seeking to engage in deeper, open-ended inquiry into a research area, in preparation for advanced research training (e.g ., Ph.D. degree) or research-focused career opportunities in a medical, academic, government, or industry laboratory setting.

Project (6 credits, Project-Based M.S.)

The Project-Based M.S. program enables students to engage in a focused, credit-based independent project experience that builds on their individual professional and academic experience. The program will facilitate development of experience, skillset, and mindset to contribute and lead in industry as engineers in a variety of biomedical engineering roles. The Project-Based M.S. program requires completion of 6 credits of BME 597. Professional Project, and completion of a capstone deliverable representative of their integrated project experience (e.g., poster or platform presentation, department seminar, final presentation, online portfolio). The Project may include one or more integrated project-based experiences:

Item #	Title	Credits
BME 5900	Internship or Co-op	0
BME 5910	Master's Design Project	0
BME 5920	Master's Clinical Preceptorship	0

In addition, the following requirements must be met for both Master of Science degree programs:

- **Technical Depth Requirement (15 credits minimum).** Thematically-related advanced engineering and science coursework in an area of technical focus within a Biomedical Engineering specialization. No more than one life sciences or regulatory course may be applied towards this requirement, and the course must be relevant to the depth area. Up to 3 credit-hours of a Thesis or Project may be designated as technical depth.
- **Seminar Requirement.** Students must take BME 591. Graduate Seminar (0 credits) and pass it twice.
- **BME Core Competencies.** In addition to meeting the specified minimum credit requirements for the degree program, all Master of Science candidates must satisfy five (5) BME Core Competencies.

1. **Mathematics.** Understanding and ability to apply fundamental principles of mathematics (e.g., statistics, numerical methods, or computational modeling).
2. **Life science.** Understanding and ability to apply fundamental principles of life science (e.g., cell and molecular biology, physiology).
3. **Clinical needs analysis and design.** Ability to communicate effectively with clinical stakeholders, understanding of healthcare systems, exposure to clinical environments and practice, understanding clinical needs and recognizing opportunities to improve healthcare delivery and practice.
4. **Regulation and controls.** Understanding of regulations and standards applied to biomedical engineering design, manufacturing, and research (e.g., medical device design regulations, FDA regulations, engineering standards, QC/QA, GMP/GLP).
5. **Value creation, innovation, technology commercialization.** Development and practice of innovation mindset and skillset to create value and recognize opportunities for innovation in the design and development of medical technologies; commercial and clinical translation of medical innovations that impact healthcare delivery and practice.

Core Competencies.

To aid students in developing a Plan of Study, the following example courses that can fulfill each of the five (5) BME Core Competencies are provided. The BME Graduate Handbook contains additional examples of courses that may fulfill these requirements. Alternative courses may be applied to fulfill competency requirements. Students need only take one (1) course to fulfill a given competency. Alternatively, waivers may be considered based on documented work experience, advanced degrees, majors, or minors that demonstrate advanced mastery in the core competency area. Course substitutions and waivers must be approved by the department Graduate Studies Committee. If approved, a Thesis or Project may be used to fulfill up to two (2) Competencies.

Mathematics

Item #	Title	Credits
MA 511	Applied Statistics for Engineers and Scientists	3
MA 501	Engineering Mathematics	3

Life Science

Item #	Title	Credits
BME 560	Physiology for Engineers	3
BME 562	Laboratory Animal Surgery	3
BME 564	Cell and Molecular Biology for Engineers	3

Regulations and Controls

Item #	Title	Credits
BME 531	Biomaterials in the Design of Medical Devices	3
BME 532	Medical Device Regulation	3

Clinical Needs Analysis and Design

Item #	Title	Credits
BME 592	Healthcare Systems and Clinical Practice	1

Value Creation, Innovation, Technology Commercialization

Item #	Title	Credits
ETR 500	Entrepreneurship and Innovation	3
ETR 593	Technology Commercialization	3
SYS 501	Concepts of Systems Engineering	3
SYS 502	Business Practices	3

Technical Depth Specializations and Example Courses.

To aid students in developing a Plan of Study that fulfills the Technical Depth requirement, we provide the following examples . These lists are not exhaustive. Students may propose alternative courses and specializations, including thematically- related courses double-counted toward a WPI Graduate Certificate, to fulfill the Technical Depth requirement (subject to review and approval by the department Graduate Studies Committee).

Biomaterials and Tissue Engineering

Item #	Title	Credits
BME 531	Biomaterials in the Design of Medical Devices	3
ME 550/BME 550	Tissue Engineering	3
BME/ME 552	Tissue Mechanics	3
BME 555	Biomedical and Tissue Microengineering	3
BME 583	Biomedical Microscopy and Quantitative Imaging	3
BME/ME 4814	Biomaterials	3
BME 4828	Biomaterials-Tissue Interactions	3
BME 4831	Drug Delivery	3
BME 4701	Cell and Molecular Bioengineering	3
CHE 521	Biochemical Engineering	3
MTE 509	Electron Microscopy	2
MTE 558	Plastics	2
MTE 511/ME 5311	Structure and Properties of Engineering Materials	2
MTE 512/ME 531	Properties and Performance of Engineering Materials	2
ME 5370/MTE 5841/MFE 5841	Surface Metrology	3
PH 561	Atomic Force Microscopy	3

Biomechanics and Medical Robotics:

Item #	Title	Credits
ME 552/BME 552	Tissue Mechanics	3
RBE 500	Foundations of Robotics	3
ME 501/RBE 501	Robot Dynamics	3
BME 520/RBE 520	Biomechanics and Robotics	3
BME 553	Biomechanics of Orthopaedic Devices	3
BME 580/RBE 580/ME 5205	Biomedical Robotics	2
BME/ME 4504	Biomechanics	3
BME/ME 4606	Biofluids	3
BME 4503	Computational Biomechanics	3

Additional Technical Depth Courses:

Item #	Title	Credits
BME 523	Biomedical Instrumentation	3
BME 581	Medical Imaging Systems	3
BME 4011	Biomedical Signal Analysis	3
BME 4201	Biomedical Imaging	3
ECE 503	Digital Signal Processing	3
ECE 5106	Modeling of Electromagnetic Fields in Electrical & Biological Systems	3
CS 583/BCB 503	Biological and Biomedical Database Mining	3
CS 534	Artificial Intelligence	3
CS 539	Machine Learning	3
CS 545/ECE 545	Digital Image Processing	3

Ph.D. in Biomedical Engineering

The Ph.D. program has no formal course requirements. However, because research in the field of biomedical engineering requires a solid working knowledge of a broad range of subjects in the life sciences, engineering and mathematics, course credits must be distributed across the following categories with the noted minimums:

- 12 credits of biomedical engineering (any BME course except BME 560, 562, or 564)
- 3 credits of life science (e.g., BME 560, 562, 564; graduate-level biology courses)
- 3 credits of advanced mathematics (e.g., MA 501, 511; graduate-level math courses)
- 3 credits of life science or advanced mathematics
- 12 credits electives
- 1 credit responsible conduct of research (usually satisfied by taking BB 551: Research Integrity in the Sciences)
- Pass BME 6999. PhD Qualifying Examination
- 30 credits dissertation research (BME 699)
- In addition, students are required to pass BME 591: Graduate Seminar four times.
- The department requires acceptance of at least one full-length, first-author publication, representing original research and based on the student's dissertation work, in a peer-reviewed venue approved by the student's PhD Dissertation Examination Committee. Students have an opportunity to petition the BME Graduate Studies Committee in cases of extenuating circumstances.

Electives may include any WPI graduate-level engineering, physics, mathematics, biomedical engineering, or equivalent course, subject to approval of the BME Graduate Studies Committee. Students may substitute 3 to 6 credits of directed research for 3 credits of biomedical engineering and/or 3 credits of electives.

Laboratory Rotations.

Students in the Ph.D. program may participate in optional laboratory rotations during their first year in the program. Laboratory rotations—short periods of research experience under the direction of program faculty members—are intended to familiarize students with concepts and techniques in several different engineering and scientific fields. They allow faculty members to observe and evaluate the research aptitudes of students and permit students to evaluate the types of projects that might be developed into dissertation projects. Upon completion of each rotation, the student presents a seminar and written report on the research accomplished. Each rotation is a 3- or 4-credit course and can last a minimum of seven weeks, or up to a full semester.

Type: Ph.D.

Business School, The

Faculty

D. Jackson, Professor of Practice and Dean; D.Min., Andover Newton Theological School; leadership efficacy realized through reflective practice and womanist leadership frameworks, womanist theology.

D. Strong, Professor and Department Head, MSIT and MSBA Program Director; Ph.D., Carnegie-Mellon University; advanced information technologies, such as enterprise systems, and their use in organizations, MIS quality issues, with primary focus on data and information quality.

S. Bossu, Visiting Assistant Professor of Finance; Ph.D., Université de Paris-Évry / Paris-Saclay; quantitative finance, radon transform.

K. Ching, Assistant Professor; Ph.D., Massachusetts Institute of Technology; entrepreneurial strategy, economics of science and innovation, science and innovation policy, digitization, data science.

S. Djamasbi, Professor and MSIUX Program Director; Ph.D., University of Hawaii at Manoa; decision making, decision support systems, information overload, decision making under crisis, affect and decision making.

M. B. Elmes, Professor; Ph.D., Syracuse University; workplace resistance and ideological control, critical perspectives on spirituality-in-the-workplace, implementation of IT in organizations, organizations in the natural environment, narrative and aesthetic perspectives on organizational phenomena, psychodynamics of group and intergroup behavior.

R. Garcia, Beswick Professor of Entrepreneurship; Ph.D., Michigan State University; entrepreneurship and benefit corporations, diversity in entrepreneurship, legitimacy of benefit corporations.

E. Gonsalves, Professor of Practice in Marketing; M.S. in Management, Worcester Polytechnic Institute; marketing, strategy, international business

A. Hall-Phillips, Associate Professor and Undergraduate Program Director; Ph.D., Purdue University; consumer behavior, business-to-business marketing, small business.

F. Hoy, Professor; Ph.D., Texas A&M University; entrepreneurship, family and small business management, strategy, international entrepreneurship.

S. A. Johnson, Professor and IE Program Director; Ph.D., Cornell University; lean process design, enterprise engineering, process analysis and modeling, reverse logistics.

R. Konrad, Associate Professor and MSOSCA Program Director; Ph.D., Purdue University; health systems engineering, patient flow optimization, health informatics, industrial engineering.

N. Kordzadeh, Assistant Professor; Ph.D., University of Texas at San Antonio; health informatics and analytics, social informatics and web 2.0, information privacy, applications of GIS in business and health care

E. Lingo, Assistant Professor; Ph.D., Harvard University; organizational studies, leadership, creativity.

F. Miller, Associate Professor; Ph.D., Michigan State University; managerial accounting and performance management.

F. Reshadi, Assistant Professor; Ph.D., West Virginia University; marketing, social media and social influence, financial and health-care decision making.

J. Ryan, Associate Teaching Professor; Ph.D., Auburn University; management information systems, health care I.T.

S. Saberi, Assistant Professor; Ph.D., University of Massachusetts-Amherst; operations, industrial engineering, supply chain management.

J. Sarkis, Professor; Ph.D., State University of New York at Buffalo; operations management, green supply chain management, sustainability.

R. Sarnie, Professor of Practice; MBA, Suffolk University; finance, financial technology.

J. Schaufeld, Affiliate Professor of Practice in Entrepreneurship; MBA, Northeastern University; entrepreneurship, technology commercialization, business acquisition and development.

P. Shah, Associate Professor and MBA/MSMG Program Director; Ph.D., Texas Tech University; marketing, brand strategy, product disposal strategy.

S. Taylor, Professor; Ph.D., Boston College; organizational aesthetics, reflective practice, leadership.

W. Towner, Associate Teaching Professor; Ph.D., Worcester Polytechnic Institute; operations management, lean manufacturing, six-sigma.

A. Trapp, Associate Professor; Ph.D., University of Pittsburgh; industrial engineering, combinatorial optimization, stochastic programming, operations research.

B. Tulu, Professor; Ph.D., Claremont Graduate University; medical informatics, V.O.I.P., information security, telecommunications and networking, systems analysis and design.

E. V. Wilson, Associate Teaching Professor; Ph.D., University of Colorado; information systems, cognitive science.

J. Zhu, Professor and Ph.D. Program Director; Ph.D., University of Massachusetts; information technology and productivity, e-business, performance evaluation and benchmarking.

Department Research

In addition to teaching, School of Business faculty are involved in a variety of sponsored research and consulting work. A sampling of current research includes: quality control in information-handling processes, supply chain management, decision/risk analysis, conflict management, capacity planning, international accounting differences, strategy and new venture teams, family and small business management, user experience, and health systems innovation.

Programs of Study

The interaction between business and technology drives every aspect of our Graduate Business Programs. We believe the future of business lies in leveraging the power of technology to optimize business opportunities. WPI stays ahead of the curve, giving students the ability to combine sound strategies with cutting edge innovation, and the confidence to contribute meaningfully within a global competitive environment. The superior record of our graduates' successes highlight why WPI enjoys a nationally-recognized reputation as one of the most respected names in technology-based business education.

WPI offers a variety of graduate business programs focusing on the integration of business and technology. The Master of Business Administration (MBA) is a highly integrated, applications-oriented program that provides students with both the 'big picture' perspective required of successful upper-level managers and the hands-on knowledge needed to meet the daily demands in the workplace. WPI's focus on the management of technology comes from the recognition that rapidly changing technology is driving the pace of business.

Students enjoy extensive opportunities to expand their networks through associations with their peers and leading high-tech organizations. They also benefit from the latest available technologies and one of the nation's most wired universities. The program's strong emphasis on interpersonal and communications skills prepares students to be leaders in any organization, and the global threads throughout the curriculum ensure that students understand the global imperative facing all businesses. Whether dealing with information technology, biotechnology, financial markets, information security, supply chain management, manufacturing, or a host of other technology-oriented industries, the real world is part of the classroom, and students explore up-to-the-minute challenges faced by actual companies, through hands-on projects and teamwork. WPI promotes an active learning process, designed to develop the very best managers, leaders and executives in a technology-dependent world.

Graduate Certificates

Graduate business certificates are designed for technical and business professionals seeking focused, in-depth knowledge within a specific area of technology management. Certificates include: Financial Technology; Health Systems Innovation; Information Security Management; Information Technology; Innovation with User Experience; Supply Chain Analytics; and Supply Chain Essentials. Each certificate consists of 4 courses, which may be double-counted toward a related master's degree. Students may also customize their own graduate business certificate. For more information, please see http://business.wpi.edu/+certificates

Admission Requirements

For the Master's program, applicants should have the analytic aptitude and academic preparation necessary to complete a technology-oriented business program. This includes a minimum of three semesters of college level math or two semesters of college level calculus. Applicants to the MSIT are also required to have a prior college-level programming course.

Applicants must have the earned equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant.

For the Ph.D. an applicant must be a graduate of an accredited U.S. college or university or an approved foreign equivalent institution, and have earned a grade point average of 3.0 or better in all prior undergraduate and graduate studies. A student with a master's degree will be expected to have successfully demonstrated graduate level knowledge in a traditional business discipline such as Accounting, Finance, Marketing, Organizational Behavior, Entrepreneurship, Information Technology, or Operations Management; or in a discipline that is relevant to the student's proposed concentration. Additionally, the applicant will demonstrate undergraduate competency in Calculus, Statistics and/or Micro/Macro Economics.

Locations

Tailored to meet the challenges of working professionals, WPI offers full- and part-time graduate business study at our campus in Worcester, Massachusetts, as well as world-wide via our online courses.

Business School Specialties

(9 credits each)

Advanced Business Analytics Methods

Degrees: BA, MBA

Item #	Title	Credits
MIS 587	Business Applications in Machine Learning	3
MKT 562	Marketing Research	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3

Advanced Operations Analytics

Degrees: OSCA, MBA

Item #	Title	Credits
	MIS 587 or MKT 562 or MKT 568	3
OIE 542	Risk Management and Decision Analysis	3
OIE 548	Performance Analytics	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3

Applied Analytics

Degrees: IUX, MBA

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 584	Business Intelligence	3
MIS 587	Business Applications in Machine Learning	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3
DS 501	Introduction to Data Science	3
	DS 502/MA 543 or MA 511	

Brands, Products and Consumers

Degrees: IUX, MBA

Item #	Title	Credits
MKT 500	Marketing Strategy	3
MKT 561	Consumer Behavior and Analytics	3
MKT 562	Marketing Research	3
MKT 565	Digital Marketing	3
MKT 568	Data Mining Business Applications	3
MKT 569	Product and Brand Management	3

Business Analytics

Degree: MBA

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 584	Business Intelligence	3
OIE 552	Modeling and Optimizing Processes	3

Data Analytics

Degrees: IT, MBA

Item #	Title	Credits
MIS 587	Business Applications in Machine Learning	3
MKT 568	Data Mining Business Applications	3
	MKT 562 or MKT 565	3

Digital Transformation

Degrees: IT, MBA

Item #	Title	Credits
MIS 500	Innovating with Information Systems	3
	OIE 501 or OIE 544 or OIE 558	3
	MIS 576 or OBC 533 or OBC 537	3

Entrepreneurship

Degree: MBA

Item #	Title	Credits
ETR 500	Entrepreneurship and Innovation	3
	Two of BUS 500, ETR 593, ETR 596	6

Information Systems Design

Degrees: IT, MBA

Item #	Title	Credits
MIS 571	Database Applications Design and Development	3
MIS 582	Information Security Management	3
MIS 585	User Experience Design	3

IT

Degree: MBA

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 581	Policy and Strategy for Information Technology and Analytics	3
MIS 584	Business Intelligence	3

IT User Experience

Degrees: IT, MBA

Item #	Title	Credits
MIS 583	User Experience Applications	3
MIS 586	User Experience Methods	3
MKT 561	Consumer Behavior and Analytics	3

Marketing Analytics

Degrees: BA, MBA

Item #	Title	Credits
	MKT 500 or MKT 561	3
MKT 565	Digital Marketing	3
MKT 568	Data Mining Business Applications	3

Operational Excellence

Degrees: OSCA, MBA

Item #	Title	Credits
	OIE 554 or OIE 558	3
	Two of FIN 500, MIS 576, OBC 537, OIE 554, OIE 558	6

Operations Analytics

Degrees: BA, MBA

Item #	Title	Credits
OIE 501	Operations Management	3
OIE 542	Risk Management and Decision Analysis	3
OIE 544	Supply Chain Analysis and Design	3
OIE 548	Performance Analytics	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

Organizing and Managing Innovation

Degrees: IUX, MBA

Item #	Title	Credits
ETR 500	Entrepreneurship and Innovation	3
ETR 593	Technology Commercialization	3
FIN 500	Financial Management	3
MIS 576	Project Management	3
OBC 505	Teaming and Organizing for Innovation	3
OBC 533	Negotiations	3
OBC 537	Leading Change	3

Product Management

Degree: MBA

Item #	Title	Credits
MKT 569	Product and Brand Management	3
	Two of ETR 593, MIS 576, MIS 583, MIS 585, MKT 565, OBC 505, OBC 533, OBC 535	6

Project Management

Degree: MBA

Item #	Title	Credits
MIS 576	Project Management	3
	Two of OBC 505, OBC 533, OBC 535, OBC 537	6

Research

Degrees: BA, IT, IUX, MBA, OSCA

Combination of the following totaling 9 credits. Max 3 credits BUS 5900.

Requires permission of Program Director:

Item #	Title	Credits
BUS 598	Independent Study	3
BUS 5900	Internship	3
BUS 698	Directed Research	

Supply Chain Management

Degrees: OSCA, MBA

Item #	Title	Credits
	OIE 549 or OIE 553	3
	Two of MKT 561, OBC 533, OIE 548, OIE 549, OIE 553	6

System Design for IUX

Degrees, IUX, MBA

Item #	Title	Credits
MIS 500	Innovating with Information Systems	3
MIS 571	Database Applications Design and Development	3
MIS 582	Information Security Management	3
IMGD 5000	IMGD Studio	3
IMGD 5300	Design of Interactive Experiences	3
RBE 526/CS 526	Human-Robot Interaction	3
	RBE 595 Synergy of Human and Robot Systems	
	WR 593 Robot Futures: Design, Ethics, Communication	

Custom

Degrees: BA, IT, IUX, MBA, OSCA

9 credits. Requires permission of Program Director.

Combined B.S./M.S. Program

This program is available to WPI undergraduate students wishing to combine one of the Business School's M.S. degrees with their B.S. A separate and complete application to the M.S. program must be submitted.

Admission to the Combined Program is determined by the School of Business. With careful planning, both degrees may be completed within the student's four years of undergraduate study.

It is recommended that the M.S. application be submitted at the end of the student's sophomore year of undergraduate study. A student in the Combined Program continues to be registered as an undergraduate until the bachelor's degree is awarded.

To obtain a bachelor's degree via the Combined Program, the student must satisfy all requirements for the bachelor's degree, including distribution and project requirements. To obtain an M.S. via the Combined Program, the student must satisfy all M.S. degree requirements. Note: no undergraduate credit may be counted toward a graduate business degree.

Please refer to the section on the Combined Programs or contact the executive director of business programs for more information.

Type: B.S./M.S.

M.S. in Business Analytics (MSBA)

The demand for knowledgeable professionals who understand both data analytics and business needs continues to increase. The MSBA program provides a solid foundation in business analytics, with applications in a variety of business areas, plus a real-world, team-based project, which ensures that students are prepared to be successful in a data-driven, technological business environment.

The MSBA is available both on-campus and online.

Type: Master of Science

Required Core Courses (3)

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 584	Business Intelligence	3
OIE 552	Modeling and Optimizing Processes	3

MSBA students must complete two three-course specialties, selected from the following specialties:

Specialty in Advanced Business Analytics Methods

Item #	Title	Credits
MIS 587	Business Applications in Machine Learning	3
MKT 562	Marketing Research	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3

Specialty in Marketing Analytics

Item #	Title	Credits
	MKT 500 or MKT 561	3
MKT 565	Digital Marketing	3
MKT 568	Data Mining Business Applications	3

Specialty in Operations Analytics

Select 3 of the following 5 courses. OIE 501 recommended for students with no operations background.

Item #	Title	Credits
OIE 501	Operations Management	3
OIE 542	Risk Management and Decision Analysis	3
OIE 544	Supply Chain Analysis and Design	3
OIE 548	Performance Analytics	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

Capstone Project Experience (2)

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
BUS 596	Master of Science Capstone Project	3

Additional Recommendations:

On-campus, international students are encouraged to complete up to three additional credits of internship to ensure their readiness for employment in the U.S.

M.S. in Information Technology (MSIT)

The demand for knowledgeable IT professionals who understand business has never been greater. The MSIT program guarantees a solid foundation in information technology and business analytics, with a wide range of cutting-edge concentrations, and how these technologies and analytics tools can best be used in a variety of business applications. The program covers principles of business, people and technology that are critical to success in technology-driven environments.

The MSIT is available both on-campus and online.

Type: Master of Science

Required Core Courses (3)

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 581	Policy and Strategy for Information Technology and Analytics	3
MIS 584	Business Intelligence	3

MSIT students must complete two three-course specialties, selected from the following specialties:

Specialty in Information Systems Design

Item #	Title	Credits
MIS 571	Database Applications Design and Development	3
MIS 582	Information Security Management	3
MIS 585	User Experience Design	3

Specialty in Data Analytics

Item #	Title	Credits
MIS 587	Business Applications in Machine Learning	3
MKT 568	Data Mining Business Applications	3
	MKT 562 or MKT 565	3

Specialty in Digital Transformation

Item #	Title	Credits
MIS 500	Innovating with Information Systems	3
	OIE 501 or OIE 544 or OIE 558	3
	MIS 576 or OBC 533 or OBC 537	3

Specialty in IT User Experience

Item #	Title	Credits
MKT 561	Consumer Behavior and Analytics	3
MIS 583	User Experience Applications	3
MIS 586	User Experience Methods	3

Capstone Project Experience (2)

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
MIS 573	System Design and Development	3

Additional Recommendations:

On-campus, international students are encouraged to complete up to three additional credits of internship to ensure their readiness for employment in the U.S.

M.S. in Innovation with User Experience (MSIUX)

Rapid advances in science and engineering allow companies to develop increasingly sophisticated IT products. As the IT industry matures, competition is increasingly shifting toward providing outstanding user experiences (UX). Innovation with UX is becoming essential in developing IT products and services that can maintain competitive advantage in the marketplace. The Business School has world-class expertise and resources in UX and is ideally positioned to prepare students as UX professionals and set them on a path to take on leaderships positions such as chief experience officers (CXO).

The MSIUX is delivered entirely online. Some courses are also available on campus.

Type: Master of Science

Required Core Courses (3)

Item #	Title	Credits
MIS 583	User Experience Applications	3
MIS 585	User Experience Design	3
MIS 586	User Experience Methods	3

MSIUX students must complete two, three-course specialties, selected from the following:

Specialty in Brands, Products and Consumers

Item #	Title	Credits
MKT 500	Marketing Strategy	3
MKT 561	Consumer Behavior and Analytics	3
MKT 569	Product and Brand Management	3

Specialty in System Design

(Select any 3; the first three are online; the others, which are not Business School courses, may not be available online)

Item #	Title	Credits
MIS 500	Innovating with Information Systems	3
MIS 571	Database Applications Design and Development	3
MIS 582	Information Security Management	3
IMGD 5000	IMGD Studio	3
IMGD 5300	Design of Interactive Experiences	3
CS/RBE 526	Human-Robot Interaction	3
	RBE 595 Synergy of Human and Robot Systems	
	WR 593 Robot Futures: Design, Ethics, Communication	

Specialty in Applied Analytics

(select any 3)

Item #	Title	Credits
MIS 502	Data Management for Analytics	3
MIS 584	Business Intelligence	3
MIS 587	Business Applications in Machine Learning	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3
DS 501	Introduction to Data Science	3
	DS 502/MA 543 or MA 511	

Specialty in Organizing and Managing Innovation

(Select any 3)

Item #	Title	Credits
FIN 500	Financial Management	3
ETR 500	Entrepreneurship and Innovation	3
ETR 593	Technology Commercialization	3
MIS 576	Project Management	3
OBC 533	Negotiations	3
OBC 537	Leading Change	3

Capstone Project Experience (2)

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
MIS 573	System Design and Development	3

M.S. in Management (MSMG)

The MSMG offers students a flexible yet focused program that will improve business skills while excelling in technology-based organizations. The MSMG is an ideal program for BS/MS students, as it provides a solid foundation in the various business discipline while allowing elective coursework from outside of The Business School.

The MSMG is available both on-campus and online.

Type: Master of Science

Required Core Courses (8)

Item #	Title	Credits
BUS 500	Business Law, Ethics and Social Responsibility	3
ETR 593	Technology Commercialization	3
FIN 500	Financial Management	3
MIS 584	Business Intelligence	3
MKT 500	Marketing Strategy	3
OBC 505	Teaming and Organizing for Innovation	3
OBC 506	Leadership	3
OIE 501	Operations Management	3

Electives (2)

(May be from outside The Business School)

M.S. in Operations and Supply Chain Analytics (MSOSCA)

The MSOSCA prepares students with the leadership skills to facilitate organizational improvement. Students explore a full range of operational topics, including risk management, lean process design, modeling & optimization, and global strategy. By learning to identify operational efficiencies of a supply chain students will be able to conduct demand forecasting, evaluate vulnerabilities and risk, and more. Students receive the skills and hands-on project management techniques necessary to design and manage an effective supply chain.

The MSOSCA is available both on-campus and online.

Type: Master of Science

Required Core Courses (3)

Item #	Title	Credits
OIE 501	Operations Management	3
OIE 544	Supply Chain Analysis and Design	3
OIE 552	Modeling and Optimizing Processes	3

MSOSCA students must complete two, three-course specialties, selected from the following:

Specialty in Supply Chain Management

select one of the following:

Item #	Title	Credits
OIE 549	Sustainable Supply Chain and Operations Management	3
OIE 553	Global Purchasing and Logistics	3

select two of the following:

Item #	Title	Credits
MKT 561	Consumer Behavior and Analytics	3
OBC 533	Negotiations	3
OIE 548	Performance Analytics	3
OIE 549	Sustainable Supply Chain and Operations Management	3
OIE 553	Global Purchasing and Logistics	3

Specialty in Advanced Operations Analytics

select one of the following:

Item #	Title	Credits
MIS 587	Business Applications in Machine Learning	3
MKT 562	Marketing Research	3
MKT 568	Data Mining Business Applications	3

select two of the following:

Item #	Title	Credits
OIE 542	Risk Management and Decision Analysis	3
OIE 548	Performance Analytics	3
OIE 559	Advanced Prescriptive Analytics: From Data to Impact	3

Specialty in Operational Excellence

select one of the following:

Item #	Title	Credits
OIE 554	Global Operations Strategy	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

select two of the following:

Item #	Title	Credits
FIN 500	Financial Management	3
MIS 576	Project Management	3
OBC 537	Leading Change	3
OIE 554	Global Operations Strategy	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

Capstone Project Experience (2)

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
OIE 597	Operations and Supply Chain Consulting Project	3

Additional Recommendations

On-campus international students are encouraged to complete up to three additional credits of internship to ensure their readiness for employment in the U.S.

Master of Business Administration (MBA)

WPI's MBA program is aimed at STEM professionals seeking the skills to strategically lead organizations. The curriculum features a 5-course core covering the business disciplines in the context of tech-driven environments; an integrative STEM course; a 3-course tech management specialization; 2 customizable electives; and a capstone course.

MBA Options

The MBA is available fully online via a mix of asynchronous and optional synchronous deliveries. Some MBA courses are also available on campus. The full MBA cannot be completed entirely on campus.

Type: M.B.A.

Required Courses (5)

Item #	Title	Credits
FIN 500	Financial Management	3
MIS 584	Business Intelligence	3
MKT 500	Marketing Strategy	3
OBC 506	Leadership	3
OIE 501	Operations Management	3

Integrative STEM Course (1)

Item #	Title	Credits
BUS 590	Strategic Management	3

MBA Specialty (3)

Elective Courses (2)

Must be Business School courses

Capstone (1)

Item #	Title	Credits
BUS 599	Capstone Project	3

Ph.D. Program

The course of study leading to the Ph.D. degree in Business Administration requires the completion of 90 credits beyond the bachelor's degree, or 60 credits beyond the master's degree. For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

Coursework

Courses in B.A. (incl. Special Topics and ISP)	15 credits
Courses in or outside of B.A.	15 credits
Dissertation Research (BUS 699)	30 credits
Other: Additional coursework (BUS 699) Additional Dissertation Research Supplemental Research (BUS 698)	30 credits

TOTAL 90 credits

For students proceeding from master's to Ph.D. degree, the 60 credits should be distributed as follows:

Coursework:

Courses in B.A. (incl. Special Topics and ISP)	12 credits
Dissertation Research (BUS 699)	30 credits
Other: Additional coursework Additional Dissertation Research (BUS 699) Supplemental Research (BUS 698)	18 credits

TOTAL 60 credits

In either case, the result of the dissertation research must be a completed doctoral dissertation. Only after admission to candidacy may a student receive credit toward dissertation research under BUS 699. Prior to admission to candidacy, a student may receive up to 18 credits of pre-dissertation research under BUS 698. All full-time students are required to register for the zero credit BUS 691 Graduate Seminar every semester.

Students formally accepted as a doctoral candidate must select a concentration in which to pursue their dissertation research. The available concentrations are listed below:

Entrepreneurship concentration:

Entrepreneurship encompasses opportunity seeking and identification, financing new enterprises, corporate venturing and other related topics. Research subjects address the conceptualization of new venture business models through to formulating exit strategies. Special areas of emphasis include intellectual property commercialization, international and cross-cultural studies, and issues associated with trans-generational entrepreneurship in family business.

Information Technology concentration:

Students will learn to use qualitative and quantitative methods to develop and apply theories regarding design, implementation, and use of advanced information systems and technologies with the goal of developing and publishing new Information Technology knowledge. Students will study information technology and how it affects individuals, organizations and society. By working closely with WPI's Information Technology scholars, students will learn to conduct theoretically sound Information Technology research that addresses real business problems, to apply for research grants, and to teach Information Technology courses. WPI's Information Technology scholars will involve Ph.D. candidates in their research activities in various organizations in the region, including those in the technology, healthcare, financial, and public sectors.

Operations Management concentration:

Students will pursue research in the areas of management sciences, operations research, business analytics, health care management, supply chain management, and decision analysis. The operations area undertakes research on decision-making through quantitative modeling of operations functions in businesses. Research topics cover all levels of business decision-making, from operation systems design and technology choices to day-to-day scheduling and performance measurement. The program emphasizes research that focuses on real business problems and maintains a balance between theory and practice. This concentration is designed to train Ph.D. students in fundamental and applied business modeling and analytical thinking.

Academic Advising

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic Plan of Study covering the first 9 credits of study. This plan should be arranged before the first day of registration. Prior to registering for any additional credits, the student must identify a permanent dissertation advisor who assumes the role of academic advisor and with whom a suitable dissertation topic and the remaining Plan of Study are arranged. Prior to completing 18 credits, the student must form a dissertation committee that consists of the dissertation advisor, at least two other business administration faculty members, and at least one member from outside the student's area of concentration. These committee members should be selected because of their abilities to assist in the student's dissertation research.

The schedule of advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan first 9 credits of study.
- Dissertation advisor—selected by student prior to registering for more than 9 credits.
- Program of study—arranged with dissertation advisor prior to registering for more than 9 credits.
- Dissertation committee—formed by student prior to registering for more than 18 credits. Consists of dissertation advisor, at least two B.A. faculty members, and at least one outside member.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Admission to Candidacy

Admission to candidacy will be granted when the student has satisfactorily passed a written exam intended to measure fundamental ability in the area of concentration and at least one additional business discipline. The two areas are selected by the student. The exam is given in January. For students who enter the program with a bachelor's degree, the exam must be taken after three semesters if they began their studies in the fall, and after two semesters if they began in the spring. For students who enter the program with a master's degree, the exam must be taken after one semester if they began in the fall, and after two semesters if they began in the spring.

Students in a WPI M.S. program who plan to apply for fall admission to the Ph.D. program are strongly advised to take the candidacy exam in January before that fall. The details of the examination procedure can be obtained from the School of Business Research Policy and Curriculum Committee.

Dissertation Proposal

Each student must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. The proposal must be made within a year of admission to candidacy. Both the written and oral proposals are presented to the dissertation committee and a representative from the School of Business Research Policy and Curriculum Committee. The prepared portion of the oral presentation should not exceed 30 minutes, and up to 90 minutes should be allowed for discussion. If the dissertation committee and the graduate committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 45 minutes allowed for discussion. Students can continue their research only if the proposal is approved.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the dissertation committee and a representative of the School of Business Research Policy and Curriculum Committee who is not on the dissertation committee. The defense is open to public participation and consists of a 45-minute presentation followed by a 45-minute open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the School of Business Research Policy and Curriculum Committee. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Type: Ph.D.

Research Specialty

Like other Business School MS specialties, the Research Specialty is a coherent set of three courses, but it is focused on research activities and contributions rather than professional knowledge and skills. Selecting a Research Specialty requires the permission of the Program Director (PD) for the MS specialty program in which the student is enrolled and a research advisor. Only one of the two specialties in a Business School MS specialty program can be a research specialty.

The Research Specialty consists of 9 credit hours, taken as a combination of the following:

BUS 5900, BUS 598 and BUS 698 may be taken multiple times for variable credit.

All 9 credits are taken under the direction of the Program Director or other approved faculty. BUS 5900 taken as part of the Research Specialty must be focused on research activity consistent with the Research Specialty, conducted in partnership with a sponsor, and under the direction of the faculty advisor for the Research Specialty. Thus, it differs from the typical student internship selected solely by a student.

Item #	Title	Credits
BUS 5900	Internship	3
BUS 598	Independent Study	3
BUS 698	Directed Research	

Student Designed Specialties

Specialties are a coherent set of three courses, selected from a defined list of three or more courses, which are available to one or more master's program. Students may request approval for a one-course substitution within an existing specialty or may create a new custom specialty. This option to make changes applies to all master's program that have specialties (the MS MG, which does not have specialties, is excluded).

Substitution of One Course within an Existing Specialty: Students may substitute one course not in the list of courses for a specialty, with permission from the Program Director for that program. The specialty should continue to be a coherent set of courses and should follow the rules of the program, e.g., the specialties in the MBA program must all be business courses.

Creation of a Custom Specialty: Students may design a custom specialty if they find that the existing specialties do not match their interests. Such a specialty must be approved by the Program Director and the GPCC (the committee responsible for graduate programs). A custom specialty must be relevant to the degree program in which the student is enrolled. Students may only create one custom specialty for their program. Examples of when a custom specialty might be appropriate include a student who is interested in (1) adding both depth and breadth by creating a specialty consisting of a second level course in multiple areas, in contrast to the existing specialties which typical focus on a single area, or in (2) focusing on a new topic by doing independent studies with a faculty member in an emerging area within their program. For the second example, if their topic is research-related within a MS program, the student might consider a Research Specialty instead of a Custom Specialty.

Chemical Engineering

NOTE: Courses listed in previous catalogs with "CM" as the prefix and the same course number as below are considered to be the SAME COURSE.

Faculty

S. C. Roberts, Professor and Department Head; Ph.D., Cornell University. Cellular engineering, plant cell culture, biotechnology, metabolic pathway engineering
T. A. Camesano, Professor; Ph.D., Penn- sylvania State University. Bacterial adhesion and interaction forces, biopolymers, bacterial/natural organic matter interactions
N. A. Deskins, Associate Professor; Ph.D., Purdue University. Energy production, nanomaterials research and development, pollution control and abatement, catalysis and chemical kinetics, and computational chemistry
D. DiBiasio, Professor; Ph.D., Purdue University. Engineering education, teaching and learning, assessment
A. G. Dixon, Professor; Ph.D., University of Edinburgh. Transport in chemical reactors, applications of CFD to catalyst and reactor design, membrane separation and reactors
N. K. Kazantzis, Professor; Ph.D., University of Michigan. Techno-economic performance analysis, sustainable design and control of chemical processes, energy production and environmental systems, valuation methods for clean energy technology options in the presence of uncertainty, process safety and chemical risk analysis
S. J. Kmiotek, Professor of Practice, Ph.D., Worcester Polytechnic Institute. Chemical process safety, air pollution control, pollution prevention
E. J. Stewart, Assistant Professor, Ph.D., University of Michigan. Biological soft matter, bacterial biofilms, biophysics of host-pathogen interactions, complex fluids, microfluidics.
A. R. Teixeira, Assistant Professor; Ph.D., University of Massachusetts Amherst. Reaction engineering, heterogeneous catalysis, microfluidic crystallization
M. T. Timko, Associate Professor, Ph.D., MIT. Renewable energy, liquid and biomass fuels, reaction engineering, fuel refining and desulfurization
E. M. Young, Assistant Professor; Ph.D., University of Texas at Austin. Synthetic biology, metabolic pathway engineering, yeast gene expression, transport protein engineering
H. S. Zhou, Associate Professor; Ph.D., University of California-Irvine. Bioanotechnology, bioseparations, micro- and nano-bioelectronics, bioMEMS, microfluidics, polymer thin films, surface modification, microelectronic and photonic packaging
W. P. Zurawsky, Associate Teaching Professor; Ph.D., University of Illinois. Membrane permeation and separations, plasma processing.

Emeritus

W. M. Clark, Professor Emeritus; Ph.D., Rice University
R. Datta, Professor Emeritus; Ph.D., University of California, Santa Barbara
Y. H. Ma, Professor Emeritus; Ph.D., Massachusetts Institute of Technology
W. R. Moser, Professor Emeritus; Ph.D., Massachusetts Institute of Technology
R. W. Thompson, Professor Emeritus; Ph.D., Iowa State University
A. H. Weiss, Professor Emeritus; Ph.D., University of Pennsylvania

Research Interests

The Chemical Engineering Department's research efforts are concentrated in the following major areas: bioengineering and biomanufacturing, materials and soft matter, energy and the environment and computational science and engineering.

Bioengineering research focuses on cellular engineering, metabolic engineering, synthetic biology bio-materials, and cell-surface interactions. Materials and soft matter research focuses on biopolymers, advanced carbon materials, biointerfaces and nano-sensors. Energy and the environment research focuses on carbon capture, biomass conversion, resource and energy efficiency, catalysis, fuel cells, reaction engineering, solar energy and zeolite synthesis. Computational science and engineering research focuses on computational fluid dynamics, genome scale modeling, molecular modeling, process systems analyses and reactor design.Master's and doctoral candidates' research in each of these areas involves the application of fundamental aspects of chemical engineering to interdisciplinary, societally relevant problems. Studies may be pursued in the following areas:

Bacterial Adhesion to Biomaterials

The mechanisms governing bacterial adhesion to biomaterials, including catheters and other implanted devices, are poorly understood; however, it is known that the presence of a biofilm on a biomaterial surface will lead to infection and cause an implanted device to fail. Research is aimed at characterizing bacterial interaction forces and adhesion to biomaterials, and developing anti- bacterial coatings for biomaterials. We are using novel techniques based on atomic force microscopy (AFM) to quantify the nanoscale adhesion forces between bacteria and surfaces.

Catalyst and Reaction Engineering

Research in this area is centered on the physical and chemical behavior of fluids, especially gases, in contact with homogeneous and heterogeneous catalysts as well as ways to improve organic and inorganic crystal growth. Projects include diffusion through porous solids, multicomponent adsorption, mechanism studies, microkinetics, reaction networks, synthesis and characterization of catalysts, catalytic reformers, electrochemical synthesis, heat and mass transfer in catalytic reactors, and simulation of catalyst surfaces and reaction sites. Experimental techniques include standard lab-scale reactors, microreactors, and in situ spectroscopic instruments to monitor chemical reactions. Applications include partial oxidation reactions, steam reforming to produce hydrogen, pharmaceuticals synthesis and conversion of bio-renewable feeds into commodity chemicals.

Fuel Cell and Battery Technology

Fuel cells have potential as clean and efficient power sources for automobiles and stationary applications. Research is being conducted on developing, characterizing and modeling of fuel cells that are robust for these consumer applications and includes development of CO-tolerant anodes, higher temperature proton-exchange membranes and direct methanol fuel cells. Ongoing research also includes reformers and membranes for production of hydrogen from liquid fuels, flow batteries for grid energy storage and fuel cells for electrochemical synthesis and reforming processes.

Soft Matter and Biointerfaces

Studies on the structure-property-function relationships within biological soft matter systems allow for advancements in the understanding of disease states as well as the development of biophysical strategies to combat disease. Our program's approach considers the physical interactions between cells, surfaces, biopolymers and their microenvironments to resolve cellular behaviors and design strategies for controlling cell growth. Our work is multidisciplinary and utilizes tools from engineering, the physical sciences, and biology. Research activities in the department are particularly focused on bacterial infection prevention and control with research thrusts in bacterial surface adhesion, mechanisms of antimicrobial peptide cytotoxicity, bacterial biofilm formation and dispersion, and in vitro models of host-pathogen interactions.

Lab-on-chip and BioMEMS

Research in the area of lab-on-chip and BioMEMS involves developing a fundamental understanding of microfluidics transport and surface reaction kinetics in the micro-and nano- domains to design and fabricate chip-based bioseparation and biosensing devices and application of bionanotechnology for rapid and sensitive molecular diagnostics. Novel nanomaterials for biomedical applications are also of interest.

Metabolic and Cellular Engineering

The goal of this research is to engineer advanced "cell factories". To accomplish this goal, researchers look to control gene expression, metabolism and protein function by writing new DNA sequences into genomes. Whether to understand fundamental questions about genetics, or to modify cells to produce valuable medicines and fuels, engineering DNA is an interdisciplinary challenge. Techniques such as next-generation sequencing, modeling, molecular biology and flow cytometry are used.

Molecular Modeling of Materials for Sustainability

Computer technologies have advanced to the point of being able to accurately determine properties of material and chemical systems. For example, catalysts involve a number of reactions that are difficult to determine using experimental techniques. Research is being conducted in the areas of photocatalysis, photovoltaics, industrial catalysis, and environmental catalysis, all with the goal of producing environmentally-safe energy and chemicals. Sample projects include determining active catalysts for CO2 photo-reduction to solar fuels, simulating alloys for fuel cells, and modeling carbon-based materials.

Plant Cell Biotechnology

Plant cells synthesize an array of sophisticated "specialized metabolites" that serve a variety of functions as human health agents, colors, flavoring and agricultural chemicals. Production of these compounds for clinical or industrial supply can be challenging due to their low yields in nature, under-defined metabolic pathways and difficult gene transformation technologies. Plant cell culture technology can be exploited not only to synthesize these valuable compounds, but also to gain fundamental insights into regulation of plant cell metabolism so that systems can be effectively engineered. By considering all scales of cellular engineering – intra, inter and extra, cultures can be designed to produce yield yields of desirable molecules.

Reactor modeling and simulation

A better understanding of interactions between reactor transport processes and chemical reaction is needed to improve reactor efficiency, which contributes to sustainable engineering. Multiscale approaches are used to give new insight into the development of catalysts and reactors, such as computational fluid dynamics (CFD) and multiphysics methods, for example microkinetics and multicomponent diffusion models can be integrated into the CFD simulations of fixed bed reactors. Applications include partial oxidation reactions, and steam reforming for generation of hydrogen and synthesis gas, one route towards the generation of clean power. Other research includes study of membrane modules for recovery of high-purity hydrogen, membrane reactors for process intensification of hydrogen generation, and new catalytic materials such as ceramic foams.

Sustainable Fuels

Transportation and shipping rely on access to affordable and abundant supplies of liquid fuels. Research is being conducted to deliver these liquid fuels in more sustainable ways, for example, using green technologies, waste feeds, and renewable feeds. The primary research tools include catalysis science, reactor design, computational modeling, and metabolic engineering. Breaking down lignocellulosic bio-polymers is one of the main technical and economic barriers preventing affordable production of biomass-derived fuels. New techniques and technologies are being developed to understand and control the de-polymerization processes. Fermentation of the resulting simple sugars is an effective method to produce hydrocarbon fuels. Here, work is on-going to develop fermenter technologies that produce drop-in biofuels, such as butanol. With conventional oil reserves dwindling, environmentally responsible upgrading of heavy oils is becoming increasingly important. Research into green technologies which reduce the energy footprint of heavy oil upgrading are being studied. Waste plastics represent an energy dense feed that is currently under-utilized. Work is ongoing to convert waste plastics into high-value monomers and liquid fuels. Likewise, food wastes are a low-cost and energy dense feedstock being studied for potential production of liquid fuels. Lastly, many of these processes co-produce a solid char material which reduces the energy yield of the oil product. Studies are ongoing to valorize these char products as waste water treatment sorbents and in other applications.

Techno-economic performance analysis, sustainable design, control and safety of chemical processes and energy systems

Current research efforts lie in the broader areas of nonlinear process techno-economic performance analysis, sustainable design, control and safety. In particular, the following thematic areas may be identified in our current research efforts: (1) Techno-economic performance assessment and technology valuation methods in the presence of uncertainty; (2) synthesis of robust digital feedback regulators for nonlinear processes; (3) design of state estimators for digital process performance monitoring and fault detection/ diagnosis purposes; (4) chemical risk assessment and management with applications to process safety; (5) development of the appropriate software tools for the effective digital implementation of the above process analysis, control, performance monitoring and risk assessment schemes

Zeolite Science and Technology

Research in the area of zeolite science is driven by the need to establish an underlying understanding of the complex phenomena driving the synthesis and applications of molecular sieve zeolites. In particular, utilizing core reaction engineering techniques to elucidate the fundamental mechanisms of zeolite nucleation and crystal growth in hydrothermal systems is of interest. Uses of zeolites as liquid and gas phase adsorbents, and as catalysts, are being studied. Incorporation of zeolites into membranes for separations is being investigated due to zeolites' very regular pore dimensions on the molecular level.

Programs of Study

Students have the opportunity to do creative work on state-of-the-art research projects as a part of their graduate study in chemical engineering. The program offers excellent preparation for rewarding careers in research, industry or education. Selection of graduate courses and thesis project is made with the aid of a faculty advisor with whom the student works closely. All graduate students participate in a seminar during each term of residence. The master's degree program in chemical engineering is concerned with the advanced topics of the field. There are three choices for students wishing to obtain advanced knowledge in chemical engineering and related fields: professional engineering option with concentration, thesis option and non-thesis option. All students must complete three of the four core courses offered in mathematics, thermodynamics, reaction engineering, and transport phenomena. In addition, they choose courses from a wide range of electives and available projects.

In the doctoral program, a broad knowledge of chemical engineering topics is required for success in the qualifying examination. Beyond this point, more intensive specialization is achieved in the student's field of research through coursework and thesis research.

Admission Requirements

An undergraduate degree in chemical engineering is preferred for master's and doctoral degree applicants. Those with related backgrounds (e.g., chemistry, biomedical engineering, physics) are also encouraged to apply. We work closely with each student on individual plans to assure they are appropriately prepared for the master's and doctoral curricula, including participation in a "boot camp" course.

Chemical Engineering Research Centers and Laboratories

Research is housed in both Goddard Hall and Gateway Park (Life Sciences and Bioengineering Center; LSBC). The LSBC is a four-story, 125,000-square-foot interdisciplinary research building that houses life sciences faculty in the departments of Biology and Biotechnology, Biomedical Engineering, Chemistry and Biochemistry, Chemical Engineering and Physics. Both Goddard Hall and LSBC are equipped with state of the art instrumentation and core facilities to support catalysis and reaction engineering work and bioengineering work, respectively. In addition, the Chemical Engineering Department participates in and/or leads a number of research center efforts on campus including the Energy Research Center, Center for Advanced Research in Drying, Biomanufacturing Education and Training Center, Fuel Cell Center, and Metal Processing Institute.

B.S./M.S. in Chemical Engineering

Double Counting. B.S.-M.S. students may double-count up to 12 credits from undergraduate or graduate courses. A maximum of four undergraduate courses may be double-counted. The undergraduate courses allowed to double-count are listed below. Students may also petition the graduate committee for other 4000-level courses to double-count. A minimum grade of "B" is required for the course to be double-counted. In order for a course to be double-counted, students must also complete an extra assignment for each course demonstrating graduate-level competence. This extra assignment may be for instance a project or a literature review. The instructor for each course should advise the student what this assignment would be after being notified that the student is double counting the course towards the B.S.-M.S. degree. Students must be accepted into the B.S.-M.S. program before courses are allowed to double-count.

Allowed Undergraduate Courses (Four Maximum Allowed to Double-Count)

- CHE 3501 Applied Mathematics in Chemical Engineering
- CHE 4405 Chemical Process Dynamics and Control Laboratory
- MQP Major Qualifying Project (1/3 unit maximum)
- An Independent Study in Chemical Engineering at the 4000 level (1/3 unit maximum)
- Only One of the Following May Count:
- CHE 4401 Unit Operations of Chemical Engineering I
- CHE 4402 Unit Operations of Chemical Engineering II
- Only One of the Following May Count:
- CHE 4404 Chemical Plant Design Project
- CHE 4410 Chemical Process Safety Design

Type: B.S./M.S.

Professional Master of Science in Chemical Engineering

A total of 30 credit hours is required. At least 24 course credit hours must be in chemical engineering including 6 credit hours of Graduate Qualifying Project (GQP), 9 credit hours chosen from the chemical engineering core curriculum, 9 credits of concentration courses, and 6 credits of chemical engineering electives. Students select a concentration in either Bioengineering or Advanced Process Engineering. Bioengineering prepares students for the biotech, pharma and medical device industries, while Advanced Process Engineering focuses on advanced topics in design, control and optimization that are applicable to a wide range of chemical processing. The credit distributions for the different concentrations are shown in Table 1.

The GQP provides a capstone experience in applying chemical engineering skills to real-world problems. GQP's are carried out in cooperation with an industrial partner and with the approval and oversight of a faculty member in Chemical Engineering.

Students must take one required three-credit concentration course plus 6 credits chosen from a list of approved concentration courses.

Students in the Bioengineering concentration must take CHE 521: Biochemical Engineering, while students in the Advanced Process Engineering concentration must take CHE 565: Advanced Process Engineering. There is flexibility in other concentration course choices so that students can further tailor their studies to their interests and needs. Courses for each of the concentrations are listed in Table 2. Students can choose additional courses to fulfill their concentration requirement as new courses become available, as long as they receive approval, in advance, from the Professional Engineering Program Director.

Thesis Option

A total of 30 credit hours is required, including 18 credit hours of coursework and at least 12 credit hours of thesis work. The coursework must include 15 credit hours of graduate level chemical engineering courses and 9 of these must be chosen from the core curriculum. A satisfactory oral seminar presentation must be given every year in residence.

Non-Thesis Option

A total of 30 credit hours is required, including a minimum of 24 credit hours in graduate level courses. At least 21 course credit hours must be in chemical engineering and 9 of these must be chosen from the core curriculum. A maximum of 6 credit hours of independent study under the faculty advisor may be part of the program. Any advanced undergraduate level courses must be approved by the departmental Graduate Committee.

Type: Master of Engineering

Table 1. Professional Engineering Option Credit Distribution

Bioengineering Concentration

Item #	Title	Credits
	3 Core Courses in CHE	9
	2 Chemical Engineering Electives	6
CHE 521	Biochemical Engineering	3
	2 Concentration Courses	6
CHE 590	Graduate Qualifying Project in Chemical Engineering	3

Advanced Process Engineering Concentration

Item #	Title	Credits
	3 Core Courses in CHE	9
	2 Chemical Engineering Electives	6
CHE 565	Advanced Process Engineering	3
	2 Concentration Courses	6
CHE 590	Graduate Qualifying Project in Chemical Engineering	3

Table 2: Possible Concentration Courses

Bioengineering

Item #	Title	Credits
BCB 501/BB 581	Bioinformatics	3
BCB 502/CS 582	Biovisualization	3
BCB 503/CS 583	Biological and Biomedical Database Mining	3
BCB 504/MA 584	Statistical Methods in Genetics and Bioinformatics	3
BB 505	Fermentation Biology	3
BB 509	Scale Up of Bioprocessing	3
BB 560	Methods of Protein Purification and Downstream Processing	3
BB 562	Cell Cycle Regulation	3
BME 523	Biomedical Instrumentation	3
ME 550/BME 550	Tissue Engineering	3
CH 538	Medicinal Chemistry	3
CH 540	Regulation of Gene Expression	2
BB 565	Virology	3
BB 575	Advanced Genetics and Cellular Biology	3
ME 552/BME 552	Tissue Mechanics	3
CE 562	Biosystems in Environmental Engineering	3

Advanced Process Engineering

CHE 504 and 509 can be used to satisfy concentration requirements if not taken as part of the core.

Item #	Title	Credits
CHE 504	Mathematical Analysis in Chemical Engineering*	3
CHE 509	Reactor Design and Kinetics*	3
CHE 531	Fuel Cell Technology	3
DS 501	Introduction to Data Science	3
FP 521	Fire Dynamics I	3
FP 553	Fire Protection Systems	3
FP 554	Advanced Fire Suppression	3
FP 555	Detection, Alarm and Smoke Control	3
FP 573	Industrial Fire Protection	3
FP 575	Explosion Protection	3
MFE 510	Control and Monitoring of Manufacturing Processes	3
MFE 520/MTE 520/ME 543	Axiomatic Design of Manufacturing Processes	3
ME/MFE/MTE 5420	Fundamentals of Axiomatic Design of Manufacturing Processes	2
MTE 558	Plastics	2
MTE 5844	Corrosion and Corrosion Control	2
ME 516	Heat Transfer	3
ME 5220	Control of Linear Dynamical Systems	2
ME 5221	Control of Nonlinear Dynamical Systems	2
SD 550	System Dynamics Foundation: Managing Complexity	3
SD 553	Model Analysis and Evaluation Techniques	3
SYS 501	Concepts of Systems Engineering	3
SYS 502	Business Practices	3
SYS 510	Systems Architecture and Design	3
SYS 512	Requirements Engineering	3
SYS 520	System Optimization	3
SYS 521	Model-Based Systems Engineering	3
SYS 540	Introduction to Systems Thinking	3

Table 3: Core Courses

Choose 3

Item #	Title	Credits
CHE 504	Mathematical Analysis in Chemical Engineering*	3
CHE 509	Reactor Design and Kinetics*	3
CHE 561	Thermodynamics*	3
CHE 571	Transport Phenomena*	3

Chemistry and Biochemistry

Faculty

A. Mattson, Professor and Department Head; Ph.D., Northwestern University; metal-free catalyst design, methodology development, complex molecule synthesis.
J. M. Argüello, Professor; Ph.D., Universidad Nacional de Río Cuarto, Argentina; transmembrane ion transport, metal-ATPases structure-function, bacterial metal homeostasis, role os metals in bacterial pathogenesis.
S. C. Burdette, Associate Professor; Ph.D., Massachusetts Institute of Technology; synthesis of fluorescent sensors for iron, photoactive chelators for delivery of metal ions in cells, applications of azobenzene derivatives with unusual optical properties, polymers to detect metal contaminants in the environment.
R. E. Dempski, Associate Professor; Ph.D., Massachusetts Institute of Technology; molecular mechanism of human zinc transporter, structure-function of light activated channel, optogenetics.
J. P. Dittami, Professor; Ph.D., Rensselaer Polytechnic Institute; medicinal chemistry, organic synthesis, new synthetic methods development.
A. Gericke, Professor; Dr.rer.nat., University of Hamburg; biophysical characterization of lipid-mediated protein function, development of vibrational spectroscopic tools to characterize biological tissue.
R. L. Grimm, Assistant Professor; Ph.D., California Institute of Technology; growth and characterization by surface science and by photoelectrochemistry of non-traditional semiconductor materials related to solar energy capture, catalysis, and conversion.
G. A. Kaminski, Associate Professor; Ph.D., Yale University; computational physical and biophysical chemistry, force field development, protein structure and binding, host-guest complex formation, solvation effects.
J. MacDonald, Associate Professor; Ph.D., University of Minnesota; porous crystalline materials composed of organic & coordination compounds, polymorphism of pharmaceutical drugs, crystallization of proteins, surpramolecular assembly on surfaces.
C. Perez Olsen, Assistant Professor; Ph.D., University of Washington; characterization of membrane composition by mass spectrometry, quantification of lipid flux with stable isotope tracers, genetic dissection of the regulatory pathways of membrane maintenance.
S. F. Scarlata, Professor, Ph.D., University Illinois Urbana-Champaign; Mechanisms of cell signaling using fluorescence imaging and correlation methods, how mechanical deformation affects calcium fluxes in cells.
P. Zhang, Assistant Professor; Ph.D., Princeton University; catalysis, methodology development, complex molecule synthesis.

Research Interests

The three major areas of research in the department are:

- Biochemistry and Biophysics. Within this area there is active research on a number of topics including heavy metal transport and metal homeostasis of both plants and bacteria, computational biochemistry/biophysics of membrane proteins, enzyme structure and function, and G protein and calcium signaling, membrane protein domains and mechanotransduction.
- Molecular Design and Synthesis. Within this area there is active research on topics encompassing organic synthesis and medicinal chemistry, supramolecular materials, metal ion sensors and chelators, polymorphism in pharmaceutical drugs, spectroscopy and photophysical properties of molecules, catalysis for C-H functionalization, and more.
- Nanotechnology and Materials. This research area encompasses such projects as photonic and nonlinear optical materials, nanoporous and microporous crystals of organic and coordination compounds, molecular interactions at surfaces, and others.

Programs of Study

The Department of Chemistry and Biochemistry offers the M.S. and Ph.D. in both Chemistry and Biochemistry. The major areas of research in the department are biochemistry and biophysics, molecular design and synthesis, and nanotechnology and materials.

Admission Requirements

A B.S. degree with demonstrated proficiency in chemistry or biochemistry is required for entrance to Chemistry and Biochemistry graduate programs.

Degree Requirements

Each student must take at least three core courses in their self-identified home track (biochemistry, inorganic, organic, physical), at least three elective courses either from an approved list of classes or pre-approved by the CBC graduate committee, as well as seminar courses. Entering students who have deficiencies in specific areas (inorganic,

organic, physical, or biochemistry), as revealed by entrance interviews, will take appropriate courses to correct these deficiencies.

Chemistry and Biochemistry Research Laboratories

The Chemistry and Biochemistry Research Laboratories are located in Goddard Hall and at Gateway Park. Department facilities and instrumentation in individual research laboratories include 500 and 400 MHz FT-NMR, GC-MS, GC, HPLC, capillary electrophoresis, DSC (differential scanning calorimeter), TGA (thermogravometric analysis), polarizing optical stereomicroscope, FT-IR, UV-VIS absorption, fluorescence and phosphorescence spectroscopy; powder and single crystal x-ray diffractometers, cyclic voltammetry, impedence spectroscopy, ellipsometer, quartz crystal microbalance, grazing incidence IR, atomic force microscope (AFM), and other surface-related facilities. Additional equipment in the biochemistry area include: centrifugues, ultra-centrifugues, PCR, phospho imager, scintillation counter, FPLC, bacteria and eukaryotic cell culture and plant growth facilities. The department is exceptionally well set up with computer facilities and is also linked to the University's network.

B.S./M.S. in Chemistry and Biochemistry

The Department of Chemistry and Biochemistry offers a combined B.S./M.S. degree option for undergraduate students currently enrolled at WPI. The university rules for B.S./M.S. programs are described in Section 5 of the undergraduate catalog and on page 21 of the graduate catalog.

The M.S. degree requirements for the B.S./M.S. program are the same as the requirements for the course work-based M.S. degree that already exists in the Department of Chemistry and Biochemistry. A B.S./M.S. degree can be completed in either 4 years (course work based M.S.) or 5 years (course work or research based M.S.). Students may formally apply to the B.S./M.S. program through the graduate admissions office or via their website.

Type: B.S./M.S.

M.S. in Chemistry or Biochemistry

For the Master of Science in Chemistry or Biochemistry, the student is required to complete a minimum of 30 graduate credit hours beyond the bachelor's degree. Students may choose between a thesis or non-thesis option. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher.

Thesis Option

The student must complete a thesis with at least 15 combined credits CH 598 (Directed Research) or CH 599 (M.S. Thesis). Additional credits may consist of any combination of thesis or course electives. Course elective credits must consist of additional CBC or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All course selections must be approved by the student's research advisor and the CBC Graduate Committee prior to registering. Each student should select a research advisor by the end of the first semester of study. M.S. candidates must submit and defend a thesis based on research conducted under the direction of a CBC faculty member. The thesis committee consists of at least three members, two of whom must belong to the CBC Department faculty.

Non Thesis Option

Graduate credits must consist of 4000-, 500- or 600-level courses. Credits should be distributed as follows:

- At least 15 credits in CBC courses.
- A maximum of 10 credits in electives in areas of engineering, science, management or mathematics.
- Students also may use up to 9 credits of CH 598 (Directed Research) toward credit hour requirements.

Biochemistry students will be advised to take graduate courses in Membrane Biophysics (CH 541), Molecular Modeling (CH 554), Medicinal Chemistry (CH 538), and Spectroscopy (CH 516) in addition to advanced Biochemistry courses. Among electives in other areas, these might include courses on applied Biochemistry/Biological processes (BB 560/ BB 505/BB 509) and Bioinformatics (BCB 501/BCB 502/BCB 503). Chemistry students will be advised to take graduate courses in Theory and Applications of NMR Spectroscopy (CH 536), Molecular Modeling (CH 554), Medicinal Chemistry (CH 538), and Spectroscopy (CH 516) in addition to advanced Chemistry courses. Among electives in other areas, these might include courses on Chemical Engineering (CHE 506/ CHE 521/CHE 561) applied Biochemistry/Biological processes (BB 560/BB 505/BB 509).

Type: Master of Science

Ph.D. in Chemistry and Biochemistry

Each student should select a research advisor by the end of the first semester of residence. By the end of the second year of residence, the student must submit a written and an oral progress report in the dissertation committee of at least four faculty members, including the Research Advisor, at least two more members of the Department, and at least one person from outside the Department. The committee will consider the student's progress and will recommend to the department whether the student should be allowed to continue toward a Ph.D.
Students who do not satisfy the academic milestones described in the Departmental Handbook (e.g., maintaining a departmental GPA over 3.0, finding a mentor, passing the qualifying exam, etc.), as determined by the department, will be dismissed from the program.

Qualifying Examination

Before formal admission to the doctoral candidacy, Ph.D. students must take the qualifying examination in their field of specialization. The examination should take place before the end of the second year of residence.

Dissertation

To fulfill the final Ph.D. degree requirement the candidate must submit and defend a satisfactory dissertation to the dissertation committee.

Type: Ph.D.

Civil and Environmental Engineering

Faculty

C. Eggleston, Professor & Department Head; Ph.D., Stanford University; natural materials and how they interact with the environment in which we live, focusing on the fundamental processes of adsorption, dissolution/ growth, electron transfer, and catalysis.
L. Abu-Lail, Assistant Professor of Teaching, Ph.D., Worcester Polytechnic Institute; Unit Operations of Chemical Engineering, Water Treatment, Hydraulics, Environmental Organic Chemistry.
L. D. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology; performance-based design of buildings, design and behavior of building structures in fire conditions, integration of design and construction.
J. Bergendahl, Associate Professor; Ph.D., University of Connecticut; industrial and domestic wastewater treatment, particulate processes in the environment, chemical oxidation of contaminants.
J. Dudle, Associate Professor; Ph.D., University of Massachusetts Amherst; surface water quality, drinking water treatment, public health.
T. El-Korchi, Professor; Ph.D., University of New Hampshire; glass fiber reinforced cement composites, tensile testing techniques, materials durability.
S. Farzin, Assistant Professor of Teaching, Ph.D., University of Massachusetts Amherst; Architectural Design, Sustainable Building Technologies, Urban Metabolism, Net Zero Emission Neighborhood, Building Energy Simulation, Art installation, Music.
S. Liu, Assistant Professor, Ph.D., University of Texas at Austin; indoor air quality, thermal comfort, building energy efficiency, computational fluid dynamics.
R. B. Mallick, Professor and White Chair; Ph.D., Auburn University; nondestructive testing, highway design, pavement material characterization.
P. P. Mathisen, Associate Professor; Ph.D., Massachusetts Institute of Technology; water resources and environmental fluid dynamics, contaminant fate and transport in groundwater and surface water, exchanges across the sediment-water interface.
N. Rahbar, Associate Professor; Ph.D., Princeton University; atomistic simulations, bioinspired design of materials, contact mechanics and adhesion, computational material science.
A. Sakulich, Associate Professor; Ph.D., Drexel University; sustainability of infrastructure materials, alternative binders, and advanced civil engineering systems.
M. Tao, Associate Professor; Ph.D., Case Western Reserve University; soil mechanics, geotechnical-pavement engineering, geo-material characterization and modeling.
S. Van Dessel, Associate Professor; Ph.D., University of Florida, Gainesville; architectural engineering, building materials.
H. Walker, Schwaber Professor of Environmental Engineering, Ph.D., University of California, Irvine; water quality, emerging contaminants, water and wastewater treatment, environmental nanotechnology, membrane processes.

Programs of Study

The Department of Civil and Environmental Engineering (CEE) offers graduate programs leading to the degrees of master of science, master of engineering and doctor of philosophy. The department also offers graduate and advanced certificate programs. Full- and part-time programs of study are available.

Master of Science and Doctor of Philosophy

The graduate programs in civil engineering and environmental engineering are arranged to meet the interests and objectives of the individual student. Through consultation with an advisor and appropriate selection from the courses listed in this catalog, independent graduate study and concentrated effort in a research or project activity, a well-planned program may be achieved. Students may take acceptable courses in other departments or those approved for graduate credit. The complete program must be approved by the student's advisor and the Graduate Program Coordinator.

The faculty have a broad range of teaching and research interests. Through courses, projects and research, students gain excellent preparation for rewarding careers in many sectors of engineering including consulting, industry, government and education.

Graduate programs may be developed in the following areas:

Structural Engineering

Courses from the structural offerings, combined with appropriate mathematics, mechanics and other courses, provide opportunities to pursue programs ranging from theoretical mechanics and analysis to structural design and materials research. There are ample opportunities for research and project work in mechanics, structures and construction utilizing campus facilities and in cooperation with area consulting and contracting firms. The integration of design and construction into a cohesive master builder plan of studies is available.

Some current and recent structural engineering research topics at WPI include: structural vibration control; structural health monitoring; system identification; design and analysis of smart structures; high impact response analysis; control and monitoring; three-dimensional dynamic response of tall buildings to stochastic winds; the inelastic dynamic response of tall buildings to earthquakes; evaluation of structural performance during fire conditions; structural design agents for building design; finite element methods for nonlinear analysis; finite element analysis of shell structures for dynamic and instability analysis; and box girder bridges.

Environmental Engineering

The environmental engineering program is designed to meet the needs of engineers and scientists in the environmental field. Coursework provides a strong foundation in both the theoretical and practical aspects of the environmental engineering discipline, while project and research activities allow for in-depth investigation of current and emerging topics. Courses are offered in the broad areas of water quality and waste treatment. Topics covered in classes include: hydraulics and hydrology; physical, chemical and biological treatment systems for water, wastewater, hazardous waste and industrial waste; modeling of contaminant transport and transformations; water quality and water resources.

Current research interests in the environmental engineering program span a wide range of areas. These areas include microbial contamination of source waters, colloid and surface chemistry, physiochemical treatment processes, disinfection, pollution prevention for industries, treatment of hazardous and industrial wastes, hydraulic and environmental fluid dynamics and coastal processes, contaminant fate and transport in groundwater and surface water, exchanges between surface and subsurface waters, and storm water quality control. Research facilities include the Environmental Laboratory and several computing laboratories. Additional opportunities are provided through collaborative research projects with nearby Alden Research Laboratory, an independent hydraulics research laboratory with large-scale experimental facilities.

Geotechnical Engineering

Course offerings in soil mechanics, geotechnical and geoenvironmental engineering may be combined with structural engineering and engineering mechanics courses, as well as other appropriate university offerings.

Engineering and Construction

Designed to assist the development of professionals knowledgeable in the design/ construction engineering processes, labor and legal relations, and the organization and use of capital. The program has been developed for those students interested in the development and construction of large-scale facilities. The program includes four required courses: CE 580, CE 584, CE 587 and FIN 500. (FIN 500 can be substituted by an equivalent 3-credit-hour course approved by the department.) It must also include any two of the following courses: CE 581, CE 582, CE 583 and CE 586. The remaining courses include a balanced choice from other civil engineering and management courses as approved by the advisor. It is possible to integrate a program in design and construction to develop a cohesive master builder plan of studies. Active areas of research include integration of design and construction, models and information technology, cooperative agreements, and international construction.

Transportation Engineering

The transportation engineering program is to provide a center for education and research for the engineers who will design, build and conduct cutting-edge research on transportation infrastructure.

The transportation engineering program is a multidisciplinary interdepartmental program designed to prepare students for careers designing, maintaining and managing transportation infrastructure systems. Students gain proficiency in transportation engineering in two complementary ways: projects and coursework. Projects focus on developing improved practical methods, procedures and techniques. Coursework is focused on practical aspects of infrastructure technology needed by practicing engineers.

Research in the transportation engineering program is sponsored by a variety of private and governmental organizations including the U. S. Federal Highway Administration, the National Cooperative Highway Research Program, the Massachusetts Highway Department, The Maine Department of Transportation, the New England Transportation Consortium, the National Science Foundation and others. Some of the more active research areas being pursued in the transportation engineering program include micro/nano characterization and micro/nano mechanics of construction materials, synthesizing 'greener' cementitious materials (geopolymers) from industrial wastes, understanding fundamental behavior of granular materials, energy harvesting from pavements, reduction of pavement temperatures and urban heat island effects, high reclaimed asphalt pavement (RAP) recycling, use of geosynthetics, phase changing materials, Superpave technology, pavement smoothness and ride quality measurement, recycled asphalt materials, and implementation of innovation in transportation management and other transportation-related topics.

Interdisciplinary M.S. Program in Construction Project Management

The interdisciplinary M.S. program in construction project management combines offerings from several disciplines including civil engineering, management science, business and economics. Requirements for the degree are similar to the master of science in engineering and construction management program.

Master of Engineering

The master of engineering degree is a professional practice-oriented degree. The degree is available both for WPI undergraduate students who wish to remain at the university for an additional year to obtain both a bachelor of science and a master of engineering, as well as for students possessing a B.S. degree who wish to enroll in graduate school to seek this degree. At present, the M.E. program is offered in the following two areas of concentration.

Master Builder

The master builder program is designed for engineering and construction professionals who wish to better understand the industry's complex decision-making environment and to accelerate their career paths as effective project team leaders.

This is a practice-oriented program that builds upon a project-based curriculum and uses a multidisciplinary approach to problem solving for the integration of planning, design, construction and facility management. It emphasizes hands-on experience with information technology and teamwork.

Environmental

The environmental master of engineering program concentrates on the collection, storage, treatment and distribution of industrial and municipal water resources and on pollution prevention and the treatment and disposal of industrial and municipal wastes.

Admission Requirements

For the M.S.

An ABET accredited B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.S. program in civil engineering. Applicants are expected to have the necessary academic preparation and aptitude to succeed in a challenging graduate program. Students who do not have an ABET accredited B.S. degree may wish to enroll in the inderdisciplinary M.S. program.

For the environmental engineering program, a B.S. degree in civil, chemical or mechanical engineering is normally required. However, students with a B.S. in other engineering disciplines as well as physical and life sciences are eligible, provided they have met the undergraduate math and science requirements of the civil and environmental engineering program. A course in the area of fluid mechanics is also required. As for the civil engineering degree program, applicants are expected to have the necessary background preparation and aptitude to succeed in a challenging graduate program. All graduates of this option will receive a master of science in environmental engineering.

For the interdisciplinary M.S. program in construction project management, students with degrees in areas such as architecture, management engineering and civil engineering technology are normally accepted to this program. Management engineering students may be required to complete up to one year of undergraduate civil engineering courses before working on the M.S.

For the M.E.

A B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.E. program in civil engineering.

For the Ph.D.

Ph.D. applicants must have earned a bachelor's or master's degree. Applicants will be evaluated based on their academic background, professional experience, and other supporting application material. As the dissertation is a significant part of the Ph.D., applicants are encouraged, prior to submitting an application, to make contact with CEE faculty performing research in the area the applicant wishes to pursue.

Civil and Environmental Engineering Laboratories

The department has five civil and environmental engineering laboratories (Environmental Lab, Geotechnical Lab, Materials/Structural Lab, Structural Impact Lab and Pavement Engineering Lab), plus three computer laboratories located within Kaven Hall. The CEE laboratories are used by all civil and environmental engineering students and faculty. The computer laboratories are open to all WPI students and faculty. Uses for all laboratories include formal classes, student projects, research projects and unsupervised student activities.

Computer Laboratories

The CEE Department has a number of computer laboratories that are located in Kaven Hall and connected to WPI's network. The computer laboratories contain up-to-date computers, network connections, and presentation systems. They are used for courses, group project work and research.

Fuller Environmental Laboratory

The Fuller Laboratory is designed for state-of-the-art environmental analyses, including water and wastewater testing and treatability studies. Major equipment includes an inductively coupled plasma mass spectrometer, total organic carbon analyzer, UV-Vis spectrophotometer, particle counter, an ion chromatograph, and two gas chromatographs. Along with ancillary equipment (such as a centrifuge, autoclave, incubators, balances, pH meters and water purification system), the laboratory is equipped for a broad range of physical, chemical and biological testing. The laboratory is shared by graduate research projects, graduate and undergraduate courses (e.g. CE 4060 Environmental Engineering Laboratory) and undergraduate projects.

Geo/Water Resources Laboratory

The geo-water resources laboratory is a flexible teaching and research space that provides support for research, undergraduate and graduate projects, and courses in the areas of geotechnical engineering and water resources. The laboratory provides bench-top laboratory space for completing soil and water quality analyses, a flexible area for working with larger lab configurations that cannot be placed on the bench-top, space for preparing equipment and supplies for field investigations, and a secure area for testing, developing, and storing both field and laboratory equipment. Laboratory equipment includes fully automated stress-path-control triaxial testing system, flexible wall permeameter, and other devices for determining basic soil properties, and an aquarium and variety of tanks for demonstrating and testing equipment in water. Field equipment includes flowmeters, pumps for groundwater sampling, multiparameter water quality monitoring, and a variety of equipment for hydrologic monitoring and water quality testing.

Materials/Structural Laboratory

The Materials/Structural Laboratory is set up for materials and structures testing. The laboratory is utilized for undergraduate teaching and projects, and graduate research. The laboratory is equipped for research activities including construction materials processing and testing. Materials tested in this lab include portland cement, concrete, asphalt, and fiber composites. The laboratory has several large-load mechanical testing machines.

Pavement Research Laboratory

The pavement research laboratory provides support for graduate research and courses. The state of the art array of equipment includes compactor, moisture susceptibility testing equipment, loaded wheel tester and extraction and recovery equipment. The laboratory contains some of the most advanced testing equipment – most notable of these are the material testing system, the Model Mobile Load Simulator, and an array of Non Destructive Testing equipment consisting of the Portable Seismic Property Analyzer, Falling Weight Deflectometer and Ground Penetrating Radar. A major focus of the pavement engineering program is on the integration of undergraduate and graduate curriculum with research projects funded by the Maine Department of Transportation, Federal Highway Administration, New England Transportation Consortium and National Science Foundation.

Structural Mechanics Impact Laboratory

The Structural Mechanics Impact Laboratory is a teaching and research laboratory. The impact laboratory is used to explore the behavior of materials and components in collisions.

The Structural Mechanics Impact Laboratory consists of the following major pieces of equipment:

- An Instron Dynatup Model 8250
- Instrumented Impact Test System,
- A high-speed video camera system,
- A data acquisition system,
- A large-mass drop tower,
- A space control desk, and
- National Instrument Lab View.

Master of Engineering in Civil Engineering

For the M.E.

The master of engineering degree requires the completion of an integrated program of study that is formulated with a CEE faculty advisor at the start of the course of study. The program and subsequent modifications thereof must be submitted to and approved by the CEE department head or the Graduate Program Coordinator, when they are developed or changed. The program requires the completion of 30 semester hours of credit. The following activities must be fulfilled through completion of the courses noted or by appropriate documentation by the department head or graduate program coordinator: experience with complex project management (CE 593 Advanced Project), competence in integration of computer applications and information technology (CE 587 Building Information Modeling), and knowledge in the area of professional business practices and ethics (CE 501 Professional Practice). The program shall also include coursework in at least two subfields of civil and environmental engineering that are related to the M.E. area of specialization.

The primary subfield will provide the student with competence required for the analysis of problems encountered in practice and the design of engineering processes, systems and facilities. Subfields are currently available in structural engineering, engineering and construction management, highway and transportation engineering, geotechnical engineering, materials engineering, geohydrology, water quality management, water resources, waste management, and impact engineering. The sub-field requirements are satisfied by completing two thematically related graduate courses that have been agreed upon by both the student and the advisor as appropriate to the program of study. In addition to the subfields noted above, other appropriate areas may be identified as long as it is clear that the courses represent advanced work and complement the program. Coursework and other academic experiences to fulfill this requirement will be defined in the integrated Plan of Study at the start of the program.

Transfer between M.S. and M.E. Program

A student may transfer from the M.E. program to the M.S. program at any time. A student may transfer from the M.S. program to the M.E. program only after an integrated program of study has been agreed upon by the student and the advisor in the area of concentration and approved by the CEE department head or the Graduate Program Coordinator.

Type: Master of Engineering

M.S. in Civil Engineering

For the M.S.

The completion of 30 semester hours of credit, of which 6 credits must be research or project work, is required. A non-thesis alternative consisting of 33 semester hours is also available. In addition to civil and environmental engineering courses, students also may take courses relevant to their major area from other departments. Students who do not have the appropriate undergraduate background for the graduate courses in their program may be required to supplement the 30 semester hours with additional undergraduate studies.

Transfer between M.S. and M.E. Program

A student may transfer from the M.E. program to the M.S. program at any time. A student may transfer from the M.S. program to the M.E. program only after an integrated program of study has been agreed upon by the student and the advisor in the area of concentration and approved by the CEE department head or the Graduate Program Coordinator.

Type: Master of Science

M.S. in Environmental Engineering

For the M.S.

The completion of 30 semester hours of credit, of which 6 credits must be research or project work, is required. A non-thesis alternative consisting of 33 semester hours is also available. In addition to civil and environmental engineering courses, students also may take courses relevant to their major area from other departments. Students who do not have the appropriate undergraduate background for the graduate courses in their program may be required to supplement the 30 semester hours with additional undergraduate studies.

Type: Master of Science

Ph.D. in Civil Engineering

For the Ph.D.

Doctoral students must satisfactorily complete a qualifying examination administered within the first 18 credits of admission into the Ph.D. program. The purpose of the qualifying examination is to assess the student's ability to succeed at the Ph.D. level and also to identify strengths and weaknesses in order to plan an appropriate sequence of courses. The exam is administered by a four member committee consisting of the major advisor and three other members selected by the major advisor.

In addition to the university requirements for the Ph.D. degree, the CEE department requires students to establish a minor and to pass a comprehensive examination. Students must establish a minor outside their major area. This may be accomplished with three courses in the approved minor area. One member of the student's dissertation committee should represent the minor area. The student's dissertation committee has the authority to make decisions on academic matters associated with the Ph.D. program. To become a candidate for the doctorate, the student must pass a comprehensive examination administered by the student's dissertation committee. The candidate, on completion and submission of the dissertation, must defend it to the satisfaction of the dissertation committee.

All full-time Ph.D. students will be required to complete the CE 596 Graduate Seminar, or equivalent, three times with a passing grade. Ph.D. students will be required to present in the Graduate Seminar at least once during their program of study.

Type: Ph.D.

Climate Change Adaptation

Faculty

S. Strauss, Director and Professor; Ph.D., University of Pennsylvania; energy, global environmental change, water and weather: risks, perceptions, and societal impacts, cultural conceptions of health and illness, transnational cultural processes and practices, mountain regions (Alps/Himalaya/Rockies), India, Switzerland, Scotland.

J. D. Dudle, Co-Director and Associate Professor; Ph.D., University of Massachusetts Amherst; surface water quality, drinking water treatment, public health.

L. Abu-Lail, Assistant Teaching Professor; Ph.D., Worcester Polytechnic Institute; unit operations of chemical engineering, water treatment, hydraulics, environmental organic chemistry.

M. Belz, Associate Teaching Professor, Ph.D. Kansas State University; cultural geography, architecture and development.

J. Bergendahl, Associate Professor; Ph.D., University of Connecticut; industrial and domestic wastewater treatment, particulate processes in the environment, chemical oxidation of contaminants.

J-M Davis, Assistant Teaching Professor; Ph.D., Memorial University of Newfoundland; geography.

J. Doiron, Assistant Teaching Professor; Ph.D., Boston University; higher education, leadership, innovation.

C. Eggleston, Professor & Department Head of Civil and Environmental Engineering; Ph.D., Stanford University; natural materials and how they interact with the environment in which we live, focusing on the fundamental processes of adsorption, dissolution/growth, electron transfer, and catalysis.

K. Foo, Assistant Teaching Professor; Ph.D., Clark University; urban geography, human-environment geography, landscape architecture.

C. B. Kurlanska, Assistant Teaching Professor, Ph.D., State University of New York at Albany; livelihood studies, community economy, social and solidarity economy, community development.

S. LePage, Instructor; M.S., Worcester Polytechnic Institute; urban and environmental planning, stormwater management, sustainable solutions to food, water and energy management.

P. P. Mathisen, Associate Professor; Ph.D., Massachusetts Institute of Technology; water resources and environmental fluid dynamics, contaminant fate and transport in groundwater and surface water, exchanges across the sediment-water interface.

S. McCauley, Associate Teaching Professor; Ph.D., Clark University; human-environment geography, urban geography, GIS.

G. Pfeifer, Associate Teaching Professor; Ph.D., University of South Florida; philosophy, social and political philosophy, global justice, and globalization.

D. Rosbach, Associate Teaching Professor; Ph.D., Virginia Tech; planning, governance and globalization.

I. Shockey, Associate Teaching Professor; Ph.D., Brandeis University; environmental sociology, climate change, ethnography

S. Stanlick, Assistant Professor; Ph.D., Lehigh University; learning sciences and technology, global citizenship

L. Stoddard, Associate Teaching Professor; Ph.D., Clark University; human-environment geography

S. Tuler, Associate Professor, Ph.D., Clark University; environmental science and policy, climate change

H. Walker, Schwaber Professor of Environmental Engineering, Ph.D., University of California, Irvine; water quality, emerging contaminants, water and wastewater treatment, environmental nanotechnology, membrane processes.

Program of Study

The Climate Change Adaptation (CCA) program offers graduate studies toward an M.S. degree, with the option for participating in the B.S./M.S. program. The CCA program builds on WPI's distinctive interdisciplinary project-based approach, giving students training to support communities and organizations as they adapt to the impacts of a changing climate around the globe. The program uses a cohort-based structure to integrate students from technical and social science background into transdisciplinary teams to gain collaborative and comparative perspectives on adaptation strategies. The program is designed to follow a full-time, cohort-based model, but limited flexibility exists to cover the coursework over a period of time longer than the prescribed 18 month model.

Admissions Requirements

Candidates for admission to the M.S. program must meet WPI's requirements, and are expected to have a bachelor's degree in social science, environmental studies/science, physical sciences, biological sciences, engineering, or other relevant field, with a minimum 3.25 GPA.

Global Project Centers

The WPI Global Projects Program allows WPI students to immerse themselves in new cultures and tackle unstructured problems in ways that are meaningful to local communities. The WPI Global Projects Program includes a diverse array of project locations in over 31 countries throughout the world. The project locations range from large international cities to small mountainside villages, and these sites serve as host locations for the GQP in the CCA program.

B.S./M.S. in Climate Change Adaptation

Students enrolled in the Bachelor's/Master's program must satisfy all the program requirements of their respective Bachelor's degree and all of the program requirements of the Master's degree in Climate Change Adaptation. A maximum of four courses may be counted toward both the undergraduate and graduate degrees. Double-counted graduate credits must be in courses, and cannot be in qualifying project work. A maximum of six graduate credits may be double-counted in Elective Courses and a maximum of six graduate credits may be double counted in Core courses. Elective courses must be at the 4000-level or above. Completion of Core courses must be pre-approved by the program because of the cohort nature of the graduate degree. A grade of B or better is required for any course to be counted toward both degrees. Acceptance into the Bachelor's/Master's program means that the candidate is qualified for graduate school, and signifies approval of the graduate credits listed for credit toward both the undergraduate and graduate degrees.

Type: B.S./M.S.

M.S. in Climate Change Adaptation

Degree Requirements

For the M.S. Community Climate Change Adaptation, the student is required to complete a minimum of 30 graduate credit hours. This includes a required non-credit orientation during the first semester. The Graduate Qualifying Project (GQP) provides a field-based experience to understand climate change impacts; forge pathways to adaptation; and enact community change. GQP's are carried out in cooperation with local partners and with the approval and oversight of faculty advisors.

Master of Science

Students pursuing an M.S. degree must complete a minimum of 30 graduate credit hours of work: 14 graduate credits of Core courses; 10 graduate credits hours of GQP; and 6 graduate credit hours of electives.

Type: Master of Science

1. Core Courses (14 graduate credits)

Item #	Title	Credits
IGS 501	Theorizing Place, Community, and Global Environmental Change	3
IGS 505	Qualitative Methods for Community-Engaged Research	2
	CE 4071 Land Use, Development and Controls	2
CE 575	Climate and the Earth System	2
IGS 510	Human Dimensions of Global Environmental Change	2
IGS 590	Capstone Seminar: Comparative Climate Action	3

2. Graduate Qualifying Project (10 graduate credits)

Item #	Title	Credits
IGS 595	Graduate Qualifying Project: Research	
IGS 599	Graduate Qualifying Project: Conference	

3. Elective Courses (minimum 6 graduate credits)

Elective courses may be chosen from the list of courses provided in the program handbook. Courses are selected based on personal interest and experience. Elective courses must be approved by the program committee prior to completion.

Computer Science

Faculty

C. E. Wills, Professor and Department Head; Ph.D., Purdue, 1988. Distributed systems, networking, user interfaces.
E. O. Agu, Professor; Ph.D., Massachusetts, 2001. Computer graphics, wireless networking, mobile computing and mobile health.
J. E. Beck, Associate Professor; Ph.D., Massachusetts, 2001. Machine learning, educational data mining, intelligent tutoring systems, human learning and problem solving.
B. J. Bohrer, Assistant Professor; Ph.D., Carnegie Mellon, 2021. Theorem-proving, cyber-physical systems, programming languages.
D. C. Brown, Professor; Ph.D., Ohio State, 1984. Knowledge-based design systems, artificial intelligence.
M. L. Claypool, Professor; Ph.D., Minnesota, 1997. Distributed systems, networking, multimedia and online games.
J. Cuneo, Instructor, MS, Georgia Institute of Technology, 2010. Computer graphics, computing for good, digital media, computers and space exploration, CS education, scientific computing.
L. De Carli, Assistant Professor; Ph.D., University of Wisconsin-Madison, 2016. Network Security, Web and Cloud Security, Threat Analysis and Detection.
D. J. Dougherty, Professor; Ph.D., Maryland, 1982. Logic in computer science, with a focus on security.
M. Y. Eltabakh, Associate Professor; Ph.D., Purdue University, 2010. Database management systems, information management.
M. Engling, Assistant Teaching Professor. Stevens Institute of Technology. 2017. Combinatorics, algorithmic complexity, formal languages
T. Guo, Assistant Professor; Ph.D., University of Massachusetts Amherst, 2016. Distributed systems, cloud computing, data-intensive systems.
L. Harrison, Associate Professor; Ph.D., University of North Carolina at Charlotte, 2013. Information visualization, visual analytics, perception-based computation for visualization.
N. T. Heffernan, The William Smith Dean's Professor; Ph.D., Carnegie Mellon, 2001. Intelligent tutoring agents, artificial intelligence, cognitive modeling, machine learning.
G. T. Heineman, Associate Professor; Ph.D., Columbia, 1996. Component-based software engineering, formal approaches to compositional design, design of algorithms.
X. Kong, Associate Professor, Ph.D., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.
D. Korkin, Professor, Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology,

data mining, machine learning.
K. Lee, Associate Professor; Ph.D., Texas A&M, 2013, Big data analytics and mining, social computing, and cybersecurity over large-scale networked information systems such as the Web, social media and crowd-based systems.
Y. Li, Associate Professor, Ph.D., University of Minnesota, 2003. Big data from complex networks, large-scale network data measurement, online social behavior modeling, spectral graph theory.
X. Liu, Associate Professor; PhD., Syracuse, 2011. Natural language processing, deep learning, information retrieval, data science, and computational social sciences.
R. Neamtu, Associate Professor of Teaching. PhD WPI, 2017. Data retrieval and management, data mining, machine learning, big data analytics and visualization, brain computer interaction, data-driven materials science, human-robot interaction.
D. Reichman, Assistant Professor; Ph.D., Weizmann Institute, 2014. Algorithms, Machine Learning, Artificial Intelligence.
C. Roberts, Assistant Professor; Ph.D., University of California at Santa Barbara, 2014. Interactive programming, audiovisual performance, music programming languages, human-centered computing.
C. Ruiz, Professor and Associate Dean; Ph.D., Maryland, 1996. Data mining, knowledge discovery in databases, machine learning.
E. A. Rundensteiner, The William Smith Dean's Professor; Ph.D., University of California, Irvine, 1992. Big data systems, big data analytics, visual analytics, machine learning/deep learning, health analytics, AI and fairness.
G. N. Sarkozy, Professor; Ph.D., Rutgers, 1994. Graph theory, combinatorics, algorithms.
C. A. Shue, Associate Professor; Ph.D., Indiana, 2009. Computer networking, security, distributed systems.
C. L. Sidner, Research Professor; Ph.D., Massachusetts Institute of Technology, 1979. Discourse processing, collaboration, human-robot interaction, intelligent user interfaces, natural language processing, artificial intelligence.
G. M. Smith, Associate Professor; Ph.D., UC Santa Cruz, 2012. Computational creativity, game design, computer science education, computational craft.
T. M. Smith, Assistant Teaching Professor, PhD., University of Connecticut, 2016. Safe Robotics and Computation for Chemical Synthesis, Data acquisition and communication for pre Hospital Care, Optimization for delivery of medical care in multi- and mass-casualty emergencies, Fairness in medical decision support systems.
E. T. Solovey, Assistant Professor; Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.
S. Taneja, Assistant Teaching Professor. Ph.D. Auburn University, 2018. Distributed computing, high-performance computing, big data systems.
R. J. Walls, Assistant Professor; Ph.D., University of Massachusetts Amherst, 2014. Systems security and privacy, digital forensics and online crime, large-scale internet measurement.
J. Weinstock, Assistant Teaching Professor. Temple University. 1997.
J. R. Whitehill, Assistant Professor; Ph.D., University of California, San Diego, 2012. Machine learning, crowdsourcing, automated teaching, human behavior recognition.
W. Wong, Assistant Teaching Professor; Ph.D., Bentley University, 2013. Healthcare information systems, Virtual Reality and Augmented Reality medical devices, software engineering methodologies, pedagogical software project innovations, computer architecture, and social networks.

Research Interests

The current departmental activities include, among other areas, analysis of algorithms, applied logic, artificial intelligence, big data, computer vision, computer graphics, database and information systems, data mining, distributed systems, graph theory and computational complexity, intelligent tutoring systems, machine learning, network performance evaluation, programming languages, robotics, security, software engineering, user interfaces, virtual reality, visualization, and Web-based systems. Research groups meet weekly and focus on topics related to the above areas. Students are encouraged to participate in the meetings related to their area(s) of interest. Research and development projects and theses are available in these areas. Computer science students may also participate in computer applications research work being conducted in a number of other departments including electrical and computer engineering, mechanical engineering, biomedical and fire protection engineering. Students are also encouraged to undertake projects and theses in cooperation with neighboring computer manufacturers or commercial organizations.

Programs of Study

Graduate programs in Computer Science provide opportunities for advanced coursework and research for highly qualified students. Graduate Certificates, recognizing completion of a cohesive set of advanced courses, are offered in several areas of Computer Science. The Master of Science degree is more comprehensive; with thesis and non-thesis (coursework-only) options, it is the degree of choice for many full-time students and working professionals. The Doctor of Philosophy degree emphasizes deeper study and discovery in preparation for a career in research or education.

Graduate programs may be undertaken on a full-time or part-time basis. For all students, challenging courses and demanding research projects, with high expectations of accomplishment, are the standard.

Admission Requirements

Applicants are expected to demonstrate sufficient background in core Computer Science for graduate-level work. Background in both theoretical and applied Computer Science, with significant programming experience and some college-level mathematics, is required. A bachelor's degree in Computer Science or a closely related field should be adequate preparation. Students from other backgrounds are welcome to apply if they can demonstrate their readiness through other means, such as the Computer Science GRE Subject exam. Work experience will be considered if it covers a broad spectrum of Computer Science at a technical or mathematical level.

A student may apply to the Ph.D. program upon completion of either a bachelor's (in which case the master's degree must first be completed as part of the Ph.D. studies) or master's degree in computer science, or with an equivalent background.

Non-matriculated students may enroll in up to two courses prior to applying for admission to a Computer Science Graduate Program.

Certificate Programs

WPI's Graduate Certificate Program provides an opportunity for students holding undergraduate degrees to continue their study in an advanced area. A B.S. or B.A. degree is the general requirement. Certificate programs require a student to complete 4-5 thematically related courses in their area of interest. Each student's program of study must be approved by the academic advisor. Academic advisors are assigned upon admission to the program but may be changed in accordance with departmental policies.
Details about the certificates available in the Department of Computer Science can be found online at https://www.wpi.edu/academics/study/computer-science-certificate

Facilities

WPI boasts excellent computing resources and network connectivity through the university's Computing & Communications Center and the CS Department's own systems. A wide range of machines provides web, mail, file, high-performance computation, and security services. An extensive software library is available free of charge to all campus users. Other specialized resources include multiple high performance and parallel-computing clusters. WPI is a member of the Internet2 consortium and WPI's campus network consists of a 10 Gigabit (on campus) backbone with multiple connections to the global internet.

Off-Campus Research Opportunities

Computer science graduate students have opportunities for research and development in cooperation with several neighboring organizations, both for the master's thesis and Ph.D. dissertation. These and other opportunities provide real-world problems and experiences consistent with WPI's policy of extending learning beyond the classroom.

B.S./M.S. in Computer Science Overview

The university rules for the B.S./M.S. program are described in Section 5 of the undergraduate catalog and on this page of the graduate catalog.

Process

Students may formally apply for admission to the B.S./M.S. program during or after taking their second 4000-level Computer Science course. Forms are available through the graduate admissions office or via their website.

Students who have entered the B.S./M.S. program, or are considering it, qualify for B.S./M.S. credit for the courses listed below.

In order to receive graduate credits for a 4000-level course, the student must earn a B course grade or higher. Course instructors may waive the course grade requirement at their discretion. Faculty may offer, at their discretion, an additional 1/6 undergraduate unit, or equivalently a 1 graduate credit, for completing additional work in the course. To obtain this credit, the student must register for 1/6 undergraduate unit of independent study at the 4000-level or a 1 graduate credit independent study at the 500-level, with permission from the instructor.

Regulations

The CS department allows all CS 4000-level undergraduate course credits to count towards the B.S./M.S. Further, with the permission of the instructor and either the Graduate Committee or the Department Chair, 4000-level Undergraduate Independent Studies may also be counted towards the B.S./M.S.

Some undergraduate and graduate courses cover similar material. Students may receive credit for both when the graduate course covers extensive material beyond the undergraduate course. The table below lists courses with significant overlap. A student can receive credit for at most one of the two courses in any row of this table.

Undergraduate Course	Graduate Course
CS 4341 Introduction to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4342 Machine Learning	CS 539 Machine Learning
CS 4432 Database Systems II	CS 542 Database Management Systems
CS 4445 Data Mining and Knowledge Discovery in Databases	CS 548 Knowledge Discovery and Data Mining
CS 4513 Distributed Systems	CS 502 Operating Systems
CS 4516 Advanced Computer Networks	CS 513 Computer Networks
CS 4518 Mobile and Ubiquitous Computing	CS 528 Mobile and Ubiquitous Computing
CS 4533 Techniques of Programming Language Translation	CS 544 Compiler Construction
CS 4536 Programming Languages	CS 536 Programming Language Design
CS 4731 Computer Graphics	CS 543 Computer Graphics
CS 4802 Biovisualization	CS 582 Biovisualization
CS 4803 Biological and Biomedical Database Mining	CS 583 Biological and Biomedical Database Mining

A B.S./M.S. student may use 1/3 unit of undergraduate credit or independent study/project work taken for B.S./M.S. credit to satisfy a bin requirement, if any of the following conditions is met: (1) The undergraduate course covers material similar to that of a graduate course that satisfies the bin. The table above provides pairs of undergraduate and graduate courses that cover similar material. The undergraduate course under consideration must appear in this table, and the corresponding graduate course must satisfy the bin requirement. (2) The course or independent study/project work is deemed to satisfy the bin by the instructor, Bin Committee, and Graduate Program Chair as indicated on the Graduate Bins Petition Form. (3) B.S./M.S. students that receive B.S./M.S. credit for one of the following courses can use that course to satisfy the corresponding bin.

- Theory: 4123 (Theory of Computation)
- Algorithms: 4120 (Analysis of Algorithms)
- Design: 4233 (OOAD), 4241 (Webware)
- Graphics/Imaging: 4732 (Animation)
- Cyber Security: 4401 (Software Security), 4404 (Tools and Techniques)
- Applications of CS: 4100 (AI for IMGD)

Type: B.S./M.S.

Master of Computer Science Program Goals and Objectives

With the growing demand for high-demand computing skills, the Master of Computer Science (MCS) provides an applied foundation in computer science. The program balances technical expertise with its application in industry. The program uses real-world experiential learning to ensure students are prepared for an evolving job market.

Admissions Requirements

Applicants are expected to demonstrate sufficient background in computing for graduate-level work. A bachelor's degree in Computer Science, Electrical Engineering, Information Technology, or other related fields should be adequate preparation. Students from other backgrounds are welcome to apply if they can demonstrate their readiness through other means, such as GRE exams, professional certifications, or relevant technical work experience.

Applicants must have the earned equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant. The GRE is not required for admission. A Statement of Purpose is not required for admission.

Non-matriculated students may enroll in up to two courses prior to applying for admission to the Master of Computer Science program.

Faculty Contacts:

George Heineman and Craig Wills.

Requirements for the Master of Computer Science (MCS)

The Master of Computer Science is an applied, terminal degree that does not provide options related to a research degree and does not include a thesis option or research seminars. The MCS degree requires at least 30 credits hours of study, i.e., ten 3-credit courses.

The MCS degree is designed to accommodate students with significant prior preparation as well as students seeking to become professionals in the field. A three-course foundation ensures incoming students have sufficient preparation for the more advanced Computer Science courses. A required design core solidifies skills in core areas of Computer Science. Students can take three elective courses, guided by several focus areas we have identified. Observe that the foundation and core classes can be specialized with electives to focus on different interests while also providing sufficient training for skilled positions in industry.

Type: Master of Computer Science

Foundation (6 credits)

MCS students may take up to two courses of foundation as follows, based on their individual preparation. Our foundation component acts as a bridge for students with less preparation to learn core concepts needed in subsequent classes. Students with significant preparation in these areas – through undergraduate classes, graduate classes, or professional experience – can take additional electives instead.

Item #	Title	Credits
CS 5007	Introduction to Applications of Computer Science with Data Structures and Algorithms	3
CS 5008	Introduction to Systems and Network Programming	3

Design Core (12 credits)

MCS students are required to complete four courses focused on design to demonstrate mastery of a broad range of design issues in Computer Science and gain essential software developer skills.

Item #	Title	Credits
CS 5084	Introduction to Algorithms: Design and Analysis	3
CS 509	Design of Software Systems	3
CS 542	Database Management Systems	3
	CS 528 or CS 546	3

Elective Courses (9 credits)

MCS students take nine additional graduate credits to complete, at most six of which can be from outside the CS department. Students may not count research-specific courses, such as CS 598, CS 599, or CS 699, towards the MCS nor may they pursue a thesis (which is available in the Master's of Science in Computer Science program). Further, students may not count CS 587, the capstone for the MS in Cyber Security, towards the MCS. Any other graduate-level CS classes not used to meet other MCS requirements may count towards the MCS electives. The following focus areas are suggestions, but students may use other graduate courses as previously described to meet the requirements.

Artificial Intelligence/Machine Learning Focus

Item #	Title	Credits
CS 534	Artificial Intelligence	3
DS/CS 541	Deep Learning	3
CS 548	Knowledge Discovery and Data Mining	3

Cybersecurity Focus

Item #	Title	Credits
CS 557	Software Security Design and Analysis	3
CS 558	Computer Network Security	3

Big Data Management Focus

Item #	Title	Credits
CS 573	Data Visualization	3
CS 585/DS 503	Big Data Management	3
CS 586/DS 504	Big Data Analytics	3

Computing Systems Focus

Item #	Title	Credits
CS 502	Operating Systems	3
CS 513	Computer Networks	3
	CS 525 Cloud Computing	3
CS 535	Advanced Topics in Operating Systems	3
CS 577/ECE 537	Advanced Computer and Communications Networks	3

Capstone Experience (3 credits)

MCS students must complete a capstone project experience as follows:

Item #	Title	Credits
CS 588	Computer Science Capstone Experience	3

With these requirements, students with no prior background may complete 2 foundation course, 4 design core courses, 3 elective courses, and the Capstone Experience for a total of 30 credits. Students with strong prior backgrounds may omit some foundation courses and instead complete additional elective courses.

M.S. in Computer Science

The M.S. program in Computer Science requires 30 credit hours of work. Students may select a non-thesis option or a thesis-option, which requires a 9-credit thesis. Each student should carefully weigh the pros and cons of these alternatives in consultation with his or her advisor prior to selecting an option, typically in the second year of study. The department will allow a student to change options only once. All entering students must submit a plan of study identifying the courses to be taken. The plan of study must be approved by the student's advisor and the CS Graduate Coordinator, and must include the following minimum requirements:

Type: Master of Science

1. Computer Science Breadth Requirement (12 credits)

M.S. students are required to achieve a passing grade in courses from four different bins, including at least three essential bins. The eleven bins are listed below, together with their corresponding courses.

Essential Bins (9 credits)

Theory (3 credits)

Item #	Title	Credits
CS 5003	Foundations of Computer Science: an Introduction	3
CS 503	Foundations of Computer Science	3
CS 521	Logic in Computer Science	3
CS 559	Advanced Topics in Theoretical Computer Science	3

Algorithms (3 credits)

Item #	Title	Credits
CS 5084	Introduction to Algorithms: Design and Analysis	3
CS 584	Algorithms: Design and Analysis	3
CS 504	Analysis of Computations and Systems	3

One course from either bin: (3 credits)

Systems

Item #	Title	Credits
CS 502	Operating Systems	3
CS 533/ECE 581	Modeling and Performance Evaluation of Network and Computer Systems	3
CS 535	Advanced Topics in Operating Systems	3

Networks

Item #	Title	Credits
CS 513	Computer Networks	3
CS 528	Mobile and Ubiquitous Computing	3
CS 529	Multimedia Networking	3
ECE 530/CS 530	High Performance Networks	3
CS 577/ECE 537	Advanced Computer and Communications Networks	3
CS 558	Computer Network Security	3

Breadth Bins (3 credits)

Courses with a 5000 number (e.g., 5003, 5084) are preparatory courses, designed specifically for students with insufficient background knowledge or skills. Graduate credit can be earned for these course and M.S. students may use them to satisfy bin requirements. However, students with a solid undergraduate degree in CS are strongly encouraged to take more advanced courses within the bins.

Note: B.S./M.S. students may satisfy this breadth requirement with fewer than 12 credits because of the credit conversion rate.

Design

Item #	Title	Credits
CS 509	Design of Software Systems	3
CS 546	Human-Computer Interaction	3
CS 562	Advanced Topics in Software Engineering	3

Compilers/Languages

Item #	Title	Credits
CS 536	Programming Language Design	3
CS 544	Compiler Construction	3

Graphics/Imaging

Item #	Title	Credits
CS 543	Computer Graphics	3
CS 545/ECE 545	Digital Image Processing	3
RBE/CS 549	Computer Vision	3
CS 563		
CS 573	Data Visualization	3

AI

Item #	Title	Credits
CS 534	Artificial Intelligence	3
CS 538	Knowledge-Based Systems	3
CS 539	Machine Learning	3
CS 540	Artificial Intelligence in Design	3
DS/CS 541	Deep Learning	3
DS/CS 547	Information Retrieval	3
CS 548	Knowledge Discovery and Data Mining	3
CS/RBE 549	Computer Vision	3
CS/SEME 566	Graphical Models for Reasoning Under Uncertainty	3

Databases

Item #	Title	Credits
CS 542	Database Management Systems	3
DS/CS 547	Information Retrieval	3
CS 561	Advanced Topics in Database Systems	3
CS 585/DS 503	Big Data Management	3
CS 586/DS 504	Big Data Analytics	3

Cybersecurity

Item #	Title	Credits
CS 557	Software Security Design and Analysis	3
CS 558	Computer Network Security	3
CS 564	Advanced Topics in Computer Security	3
CS 571	Case Studies in Computer Security	3
CS 578/ECE 578	Cryptography and Data Security	3
CS 673/ECE 673	Advanced Cryptography	3

Applications of CS

Item #	Title	Credits
RBE 526/CS 526	Human-Robot Interaction	3
SEME/CS 565	User Modeling	3
SEME/CS 567	Empirical Methods for Human-Centered Computing	3
SEME/CS 568	Artificial Intelligence for Adaptive Educational Technology	3
CS 582/BCB 502	Biovisualization	3
CS 583/BCB 503	Biological and Biomedical Database Mining	3

2. Computer Science Electives (18 credits)

M.S. students must complete sufficient course work selected from CS courses at the 500-level or independent study. With the permission of the academic advisor, a student may take a total of at most six graduate credits from outside of Computer Science towards the M.S. degree. Courses in college teaching may not be counted towards the 30 credits required for a CS Master's degree.

Thesis Option

A thesis consisting of a research or development project worth a minimum of 9 credit hours must be completed and presented to the faculty. A thesis proposal must be approved by the department by the end of the semester in which a student has registered for a third thesis credit. Proposals will be considered only at regularly scheduled department meetings.

Students funded by a teaching assistantship, research assistantship or fellowship must complete the thesis option.

Non-thesis Option

A total of at least 30 credit hours must be satisfactorily completed, including four courses which satisfy the Breadth Requirement. Students should endeavor to take these four courses as early as possible so as to provide the background for the remaining graduate work.

The non-thesis option is not applicable to students funded by a teaching assistantship, research assistantship or fellowship.

M.S. in Computer Science specializing in Computer Security Program of Study

A specialization in computer security is available within the master's degree program of the Computer Science (CS) Department.

Students enrolled in this specialization will receive the master of science degree in computer science, with a notation on their transcript "Specialization in Computer Security." The program is focused on preparing students for both industrial positions and Ph.D. study related to computer security.

WPI's cyber-security programs place the science and engineering of security within the broader holistic frameworks of institutions and society. The specialization in Computer Science prepares students to approach technical computer security problems in the context of users and organizations. The M.S. specialization in computer security strives to produce students who

- can assess which security-related threats to address in a computing problem
- understand technical security vulnerabilities and technologies at least two different abstraction levels within computing systems
- appreciate behavioral and human factors in creating feasible security systems

Admission Requirements

The program is conducted at an advanced technical level and requires, in addition to the WPI admissions requirements, a solid background in computer science (CS). Normally a B.S. degree in CS is expected; however, applicants with comparable backgrounds, together with expertise gained through work experience, will also be considered. Interested students should apply to the CS master's degree program. Admission decisions are made by the CS department.

Degree Requirements

33 credits

The Computer Security specialization has both coursework-only and thesis options. The program distribution requirements are as follows:

- Security Core: 6 credits
- Security Electives: 6 credits for the coursework option, or 3 credits for the thesis option. At least one elective course must emphasize Behavioral Dimensions of security.
- Business/Management: 3 credits
- Computer Science Bins: 12 credits
- Either 6 credits of general CS electives (coursework option) or 9 credits of M.S. thesis (thesis option)

The following courses satisfy each requirement:

Security Core: Courses covering two of software, systems/networks, and wireless/internet level security. Current applicable courses are:

- CS 557 (Software Security Design and Analysis)
- CS 558 (Network Security)
- ECE 579W (Wireless and Internet Security)

Students with B.S./M.S. credit for CS 4401 (Software Security Engineering) or CS 4404 (Tools and Techniques in Computer Network Security) may apply at most one of these courses towards the security core requirement for the M.S. specialization.
Security Electives: Includes all security-related courses offered in Computer Science and Electrical and Computer Engineering. Up to three credits from thesis work on a security-related topic may count towards this requirement, with the approval of the specialization director. Current applicable courses are the security core courses as well as:

- CS 571 (Case Studies in Computer Security) [satisfies Behavioral Dimensions requirement]
- CS 578 (Cryptography)
- CS/ECE 673 (Advanced Cryptography)
- CS 564 (Advanced Topics in Computer Security)
- Special topics courses with the approval of the specialization director

At least one course counted towards security electives must provide significant coverage of behavioral dimensions of cyber security. Permanent course offerings that satisfy the behavioral dimensions requirement are designated as such in their catalog descriptions. The instructors of topics courses (CS 525 and CS 5XX) and independent study courses may designate particular offerings as satisfying the behavioral requirement with the approval of the Specialization Director.

Business/Management: Courses covering business or management issues that bear on security concerns. Current applicable courses are:

- MIS 582 (Information Security Management)
- OIE 542 (Risk Management and Decision Making)

Computer Science Bins: Courses as required to satisfy the breadth requirements ("bins") for the CS M.S. degree. Details appear in the CS M.S. degree requirements.

Electives: Any courses allowable within the requirements for CS M.S. degrees, including thesis credits.

Thesis Approval: If a student applies thesis credits towards a degree bearing the computer security specialization, his or her thesis topic must be approved as security-related by one of the core specialization faculty. Theses need not be advised by core specialization faculty; in such cases, the reader should be one of the core specialization faculty.

Important Note

Since the security specialization is within the master's programs of the Computer Science Department, students in this specialization must also satisfy all requirements of the computer science master's program. There is a limit to the number of courses outside of Computer Science that students may apply towards their Computer Science master's degree.

Type: Master of Science

Ph.D. in Computer Science

Students are advised to contact the department for detailed rules, as there are departmental guidelines, in addition to the university's requirements, for the Ph.D. degree.

Upon admission, the student is assigned an academic advisor and together they design a Plan of Study during the first semester of the student's Ph.D. program.

The student must satisfy the Ph.D. Qualifying Requirement, consisting of the Breadth Requirement and the Research Qualifying Requirement. These requirements are described in the Graduate Regulations on the CS department website https://web.cs.wpi.edu/Intranet/Graduate/guide.html.

Upon successful completion of the Ph.D. qualifying requirement, the student becomes a computer science Ph.D. candidate. The student's Dissertation Committee must be formed within the first year of candidacy. The student selects a research advisor from within the CS department, and together they select, with the approval of the CS Graduate Committee, three additional members, at least one of whom must be from outside the WPI CS department. The Dissertation Committee will be responsible for supervising the comprehensive examination, and approving the dissertation proposal and final report.

The Ph.D. degree requirements consist of a coursework component and a research component, which together must total at least 60 credit hours beyond the master's degree requirement. For students who earned a MS degree in CS at WPI during the period when that MS degree program required 33 credits, the coursework and research component for the Ph.D. degree must total at least 57 credit hours.

The coursework and research component must total at least 57 credit hours for students who earn both a master's degree and Ph.D. degree in CS at WPI. The coursework component must include 1) the completion of the student's Ph.D. Breadth Requirements and 2) 15 graduate credits in Computer Science courses, independent studies, or directed research (these 15 credits may include credits earned as part of completing the Ph.D. Breadth Requirements). Coursework credits taken outside Computer Science must be approved by the student's advisor.

The student may also enroll for research credits, but is only allowed up to 18 directed research credits prior to the completion of the Ph.D. candidacy requirements. The Ph.D. candidacy requirements are the completion of the Ph.D. Breadth Requirements and the Ph.D. Research Qualifier. With the approval of the Dissertation Committee, the student applies for and takes the Ph.D. comprehensive examination. This examination must be passed prior to the completion of the dissertation defense and is normally taken after some initial dissertation research has been performed. With approval of the Dissertation Committee, the student applies for and takes the dissertation proposal examination, usually within one year of the Ph.D. candidacy.

The Ph.D. research component consists of at least 30 credits (including any research credits earned prior to the acceptance of the dissertation proposal and excluding any research credits applied toward a master's degree) leading to a dissertation and a public defense, which must be approved by the student's Dissertation Committee.

Ph.D. Breadth Requirements

Ph.D. students are required to achieve at least a B grade in courses from six different bins (listed earlier in the CS Breadth Requirement for the M.S. Degree). These six bins must include all three essential bins. Students must achieve an A grade in at least four of the six bins, including an A grade in at least one essential bin.

Courses with a 5000 number (e.g., 5003, 5084) are "preparatory courses", designed specifically for students with insufficient background knowledge or skills. While graduate credit can be earned for these courses, they cannot be used by Ph.D. students to satisfy a bin requirement.

The Ph.D. breadth requirement must be satisfied by the time the student achieves the following number of graduate credits: for PhD-90: 54 credits (18 courses); for PhD-60: 36 credits (12 courses).

Students admitted to the CS Ph.D. program with only a bachelor's degree (i.e., PhD-90) must complete a CS MS degree as the first step towards the Ph.D. However, the Ph.D. breadth requirement is more demanding than the MS breadth requirement. Consequently, those students should satisfy the Ph.D. breadth requirement instead while obtaining the MS degree. All other requirements for the M.S. degree remain the same.

Type: Ph.D.

Cyber Security

B.S./M.S. in Cyber Security For the Joint Bachelor's/Master's Program

The requirements for the MS-SEC are structured so that undergraduate students would be able to pursue a Bachelor's/Master's program, in which the Bachelor's degree is awarded in any major offered at WPI and the Master's degree is awarded as the MS-SEC. Students enrolled in the joint Bachelor's/Master's program must satisfy all the program requirements of their respective bachelor's degree and all the program requirements of the MS-SEC. WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelor's/Master's program. This overlap can be achieved through the following mechanisms. Students may double-count courses towards both their undergraduate and graduate degrees whose credit hours total no more than 40 percent of the 30 credit hours required for the MS-SEC, and that meet all other requirements for each degree. These courses can include graduate courses as well as certain undergraduate 4000-level courses as long as the undergraduate courses are acceptable in place of a corresponding graduate course that satisfies a MS-SEC requirement.

In consultation with the academic advisor, the student prepares a Plan of Study outlining the selections chosen to satisfy the Bachelor's/Master's program degree requirements, including the courses that will be double-counted. This Plan of Study must then be approved by the Cyber Security program. As a university wide rule, the B.S./M.S. double counting credits can be applied for only while the student is an undergraduate student.

For the following 4000-level courses, two graduate credits will be earned towards the joint Bachelor's/Master's degree if the student achieves grade B or higher, or otherwise with the instructor's approval. In addition, faculty may offer, at their discretion, an additional 1/6 undergraduate unit, or equivalently a 1 graduate credit, for completing additional work in the course. To obtain this additional credit, the student must register for 1/6 undergraduate unit of independent study at the 4000-level or a 1 graduate credit independent study at the 500-level, with permission from the instructor. A student can receive credit for at most one of the two courses in any row of the following table.

Undergraduate Course	Graduate Course
CS 4341 Intro to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4342 Machine Learning	CS 539 Machine Learning
CS 4401 Software Security Engineering	CS 557 Soft. Security Design & Analysis
CS 4432 Database Systems 2	CS 542 Database Management Systems
CS 4445 Data Mining and Knowledge Discovery in Databases	CS 548 Knowledge Discovery and Data Mining
CS 4513 Distributed Systems	CS 502 Operating Systems
CS 4516 Advanced Computer Networks	CS 513 Computer Networks

Students may additionally double-count CS 4404 (Tools and Techniques in Computer Network Security) or CS 4801/ECE 4802 (Introduction to Cryptography and Communication Security) towards the joint Bachelor's/Master's degree.

Other 4000-level courses not listed above, including 4000-level independent study courses, require a petition and approval from the Cyber Security Graduate Committee before they can double-count for the Bachelor's/Master's degree.

Satisfying MS-SEC Core Areas

Students with Bachelor's/Master's credit for CS 4401 (Software Security Engineering), CS 4404 (Tools and Techniques in Computer Network Security), or CS 4801/ECE 4802 (Introduction to Cryptography and Communication Security) may use that course to satisfy the technically-focused core course requirement. Alternatively, the student may instead apply that course credit towards either the depth or the elective requirements. For any other undergraduate course or independent study/project work, students may submit a petition along with a detailed course description and syllabus to the Cyber Security Program for final decision on whether the course should count towards core area requirements.

Type: B.S./M.S.

M.S. in Cyber Security

Program Goals and Objectives

With the growing demand for expertise in Cyber Security, the Master of Science in Cyber Security (MS-SEC) provides a foundation in computing and security. The program balances technical expertise with its application in industry and government spaces. The program uses real-world experiential learning and research opportunities to ensure students are prepared for an evolving threat landscape.

Admissions Requirements

Applicants are expected to demonstrate sufficient background in computing for graduate-level work. Background in developing or using software tools is required. A bachelor's degree in Computer Science, Electrical Engineering, Information Technology, or other related fields should be adequate preparation. Students from other backgrounds are welcome to apply if they can demonstrate their readiness through other means, such as GRE exams, professional certifications, or relevant technical work experience.

Applicants must have earned the equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant. The GRE is not required for admission.

Non-matriculated students may enroll in up to two courses prior to applying for admission to the Master of Science in Cyber Security.

Faculty Contacts:

Andrew Clark, Lorenzo De Carli, Yarkin Doroz, Daniel Dougherty, Fatemeh Ganji, William Martin, Koksal Mus, Patrick Schaumont, Craig Shue, Berk Sunar, Robert Walls, and Craig Wills.

Requirements for the Master of Science in Cyber Security (MS-SEC)

The Master of Science in Cyber Security allows students to pursue research or focus on applied courses that address security problems. Students may choose to complete either a capstone project or a MS thesis. The degree requires at least 30 credits hours of study, i.e., a minimum of ten 3-credit courses.

The MS-SEC is designed to accommodate students with significant prior preparation as well as those seeking to become professionals in the field. It supports both a standard and an advanced track of study. These tracks are for advising purposes only; students on either track earn the same credential and the selected track is not officially recorded. Under each track, students are encouraged to focus on either a software-centric or hardware-centric collection of courses.

Type: Master of Science

MS-SEC students may take up to three bridge courses from:

Item #	Title	Credits
CS 5007	Introduction to Applications of Computer Science with Data Structures and Algorithms	3
CS 5008	Introduction to Systems and Network Programming	3
CS 509	Design of Software Systems	3

MS-SEC students must complete a three-course core focused on technical, human behavior, and business:

- One technically-focused course from:

Item #	Title	Credits
CS 557	Software Security Design and Analysis	3
CS 558	Computer Network Security	3
DS/ECE 577	Machine Learning in Cybersecurity	3
	ECE 579S Computer Security	
	ECE 579C Applied Cryptography and Physical Attacks	

- One human behavior-focused course from:

Item #	Title	Credits
CS 571	Case Studies in Computer Security	3
	CS 525 Digital Forensics	
	CS 525 Computer Crime Law	
	ECE 579B Blockchain and Cryptocurrencies	

- MIS 582 Information Security Management

Item #	Title	Credits
MIS 582	Information Security Management	3

MS-SEC students must complete three depth courses from the following:

Item #	Title	Credits
CS 578/ECE 578	Cryptography and Data Security	3
CS 673/ECE 673	Advanced Cryptography	3
CS 564	Advanced Topics in Computer Security	3
OIE 542	Risk Management and Decision Analysis	3
	Any core course from above that has not been used to satisfy the core requirement.	

In the standard track, our bridge component supports students with less preparation to help them learn core concepts needed in subsequent classes. While highly recommended for those without previous technical preparation related to the field, these courses are optional preparation. Students who already have significant preparation in these areas, through undergraduate classes, graduate classes, or professional experience may choose not to take one or more bridge course without requiring advisor or program approval. For students on the software-centric standard track, CS 5007, CS 5008, and CS 509 are useful preparation.

In the advanced track, students may choose not to take any of the bridge courses and instead focus on technical depth or electives. Students on the advanced software-centric track may prefer to take either CS 557 or CS 558. Students on the advanced hardware-centric track may prefer to take DS/ECE 577 Machine Learning in Cybersecurity or ECE 579C Applied Cryptography and Physical Attacks.

MS-SEC students who do not take all of the bridge courses may select to take thesis credits or additional elective courses from the following to reach the 30-credit requirement:

Item #	Title	Credits
CS 502	Operating Systems	3
CS 513	Computer Networks	3
CS 534	Artificial Intelligence	3
CS 539	Machine Learning	3
CS 542	Database Management Systems	3
CS 546	Human-Computer Interaction	3
CS 548	Knowledge Discovery and Data Mining	3
CS 573	Data Visualization	3
ECE 506	Introduction to Local and Wide Area Networks	3
ECE 5307	Wireless Access and Localization	3
	Undergraduate courses through the BS/MS program that have significant material overlap with the above graduate courses, as specified in the following section.	
	Any core or depth course from above that has not been used to satisfy either the core or depth requirements.	

MS-SEC students must complete a three-credit capstone project experience or a nine-credit MS Thesis from the following:

Item #	Title	Credits
CS 587/ECE 588	Cyber Security Capstone Experience	3
CS 599	Master's Thesis	3
ECE 599	Thesis	3

In the core requirements, students are exposed to a technically-oriented course, a human behavioral dimension course, and a course that relates security to business needs. This combination allows students to put technical material into a societal context.

With these requirements, students on the standard track may complete 3 bridge courses, 3 core courses, 3 depth courses, and the capstone experience for a total of 30 credits. Students on the advanced track may omit the bridge courses and instead take 3 core courses, 3 depth courses, 3 elective courses, and the capstone experience totaling 30 credits. For students pursuing a thesis, the capstone and two elective courses may be swapped for a 9-credit MS thesis.

Data Science

Faculty

E. A. Rundensteiner, The William Smith Dean's Professor, Computer Science and Program Director, Data Science. Ph.D., University of California, Irvine, 1992. Big data systems, big data analytics, visual analytics, machine learning/deep learning, health analytics, AI and fairness.
M. Eltabakh, Associate Professor, Computer Science Department. Ph.D., Purdue University, 2010. Database management systems and information management, query processing and optimization, indexing techniques, scientific data management, and big data analytics.
F. Emdad, Teaching Professor, Data Science Program. Ph.D., Colorado State University, 2007. Business analytics, computational and applied mathematics.
T. Ghoshal, Assistant Teaching Professor, Data Science Program. Ph.D., University of Mississippi, 2020. Feature Engineering, Deep Learning, and Natural Language Processing.
L. Harrison, Associate Professor, Computer Science Department. Ph.D., University of North Carolina, 2013. Data visualization, visual analytics, human computer interaction.
X. Kong, Associate Professor, Computer Science Department, Ph.D., University of Illinois, 2014. Data mining and big data analysis, with emphasis on addressing the data variety issues in biomedical research and social computing, and healthcare analytics.
N. Kordzadeh, Ph.D., University of Texas at San Antonio. Assistant Professor of Information Systems,WPI Business School. Organizational and individual adoption and use of social media in healthcare; business intelligence and analytics with an emphasis on algorithmic fairness and ethical decision-making.
K. Lee, Associate Professor, Computer Science Department, Ph.D., Texas A&M University, 2013. Big data analytics and mining, social computing, and cybersecurity over large-scale networked information systems such as the Web, social media and crowd-based systems.
Y. Li, Associate Professor, Computer Science Department, Ph.D., University of Minnesota, 2013. Ph.D., BUPT, Beijing, China, 2009. Data mining and artificial intelligence with applications in urban computing, smart transportation, and human mobility analysis.
X. Liu, Associate Professor, Computer Science Department. Ph.D., Syracuse University, 2011. Natural language processing, deep learning, information retrieval, data science, and computational social sciences.
O. Mangoubi, Assistant Professor, Mathematical Science Department. PhD, Massachusetts Institute of Technology, 2016. Optimization, Machine learning, Statistical algorithms.
C. Ngan, Assistant Teaching Professor, Data Science, Ph.D., George Mason University, 2013. Time Series Analysis, Decision Guidance and Support Systems.
R. C. Paffenroth, Associate Professor, Mathematical Sciences Department, Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.
C. Ruiz, Professor, Computer Science Department. Ph.D., University of Maryland, 1996. Data mining, machine learning, artificial intelligence, health, clinical medicine.
D. M. Strong, Professor and Department Head, WPI Business School. Ph.D., Carnegie Mellon University, 1988. Healthcare and business data analytics, computing applications in organizations.
A. C. Trapp, Associate Professor, WPI Business School. Ph.D., University of Pittsburgh, 2011. Mathematical optimization and analytics with applications to benefit society, focusing on improving outcomes of vulnerable populations.
R. Zekavat, Professor, Physics Department, Ph.D., Colorado state University, 2002. Statistical Signal Processing, Sensor Data Analysis and Machine Learning.
J. Zou, Associate Professor, Mathematical Sciences Department. Ph.D., University of Connecticut, 2009. Financial time series and spatial statistics with applications to epidemiology, public health and climate change.

Affiliated Faculty

E. O. Agu, Professor, Computer Science Department. Ph.D., University of Massachusetts, 2001. Mobile and ubiquitous health, machine and deep learning applications, and computer graphics.

J. Beck, Associate Professor, Computer Science Department. Ph.D., University of Massachusetts, 2001. Educational data mining.

M. Y. Blais, Associate Teaching Professor and Associate Department Head, Mathematical Sciences. Ph.D., Cornell University, 2006. Liquidity modeling, operations research, volatility derivatives, leverage.

D. Brown, III, Professor and Department Head, Department of Electrical and Computer Engineering. Ph.D., Cornell University, 2000. Communication systems and networking, signal processing, information theory.

L. Capogna, Professor, Mathematical Sciences. Ph.D., University of Purdue, 1996. Partial differential equations, calculus of variations and analytic aspects of quasiconformal mappings, sub-Riemannian geometry, minimal surfaces and mean curvature flow.

S. Djamasbi, Professor, WPI Business School. Ph.D., University of Hawaii, 2004. Management information systems.

J. Doyle, Associate Professor, Social Science and Policy Studies. Ph.D., University of Colorado-Boulder, 1991. Mental models of complex systems, environmental cognition and behavior.

M. Elmes, Professor, WPI Business School. Ph.D., Syracuse University, 1998. Interpersonal and group dynamics in complex organizations, leading change, leadership ethics.

B. Faber, Professor, Humanities & Arts Department. Ph.D., English University of Utah, 1998. Organizations and change, health care operations and data-intensive methods for understanding health systems and medical practices.

L. Fichera, Assistant Professor; Ph.D., University of Genoa/ Italian Institute of Technology.Continuum robotics, medical robotics, surgical robotics, image-guided surgery, laser-based surgery, medical devices.

T. Guo, Assistant Professor, Computer Science; Ph.D., University of Massachusetts Amherst, 2016. Distributed systems, cloud computing, data-intensive systems.

A. Hall-Phillips, Associate Professor, WPI Business School. Ph.D., Purdue University, 2011. Consumer behavior, business-to-business marketing, small business.

N. T. Heffernan, Professor, Computer Science Department and Co-Director Learning Sciences and Technologies. Ph.D., Carnegie Mellon University, 2001. Educational data mining, Machine Learning applied to educational context. A/B testing.

X. Huang, Professor, Department of Electrical and Computer Engineering. Ph.D., Virginia Tech, 2001. Reconfigurable computing, ubiquitous computing and RFID.

M. Humi, Professor, Mathematical Sciences. Ph.D., Weizmann Institute of Science, Rehovot, Israel, 1969. Development and application of mathematical methods to atmospheric research and satellites orbits.

S. Johnson, Professor, WPI Business School. Ph.D., Cornell University, 1989. Healthcare delivery processes, EHR systems, process analysis and demand.

R. Konrad, Associate Professor, WPI Business School. Ph.D., Purdue University, 2009. Decision-analytic modeling, discrete event stochastic simulation-based optimization.

D. Korkin, Professor in Computer Science, and BCB Program Director; Ph.D., University of New Brunswick, Canada, 2003. Big data analytics in life sciences, machine learning and its applications, visualization of complex biological data, network science, bioinformatics and personalized medicine.

F. Miller, Associate Professor, WPI Business School. Ph.D., -Michigan State University, The Eli Broad School of Management, 2007. Accounting, psychology and economics interact.

R. Neamtu, Associate Teaching Professor, Computer Science; Ph.D., Worcester Polytechnic Institute.

S. D. Olson, Professor and Department Head, Mathematical Sciences. Ph.D., North Carolina State University, 2008. Mathematical biology, chemical signaling, mechanics, and hydrodynamics.

M. Radzicki, Associate Professor, Social Science and Policy Studies. Ph.D., University of Notre Dame, 1985. System dynamics modeling, agent-based modeling, predictive analytics.

E. Ryder, Associate Professor, Biology and Biotechnology. Ph.D., Harvard University, 1993. Developmental neurobiology, genetics, bioinformatics, computational biology.

A. Sales, Assistant Professor, Mathematical Sciences. Ph.D., University of Michigan, 2013. Methods for causal inference using administrative or high-dimensional data, especially in education.

M. Sarkis, Professor, Mathematical Sciences. Ph.D., New York University, 1994. Numerical analysis, finite element methods

G. Sarkozy, Professor, Computer Science Department. Ph.D., Rutgers University, 1994. Graph theory, discrete mathematics, and theoretical computer science.

S. Sturm, Associate Professor, Mathematical Sciences. Ph.D., Technical University of Berlin, Germany, 2010. Financial mathematics and engineering.

B. Sunar, Professor, Department of Electrical and Computer Engineering. Ph.D., Oregon State University, 1998. Cryptography, network security, high performance computing

D. Tang, Professor, Mathematical Sciences. Ph.D., University of Wisconsin-Madison, 1988. Computational biomathematics, biology and bioengineering.

S. Taylor, Professor, WPI Business School. Ph.D., Boston College, 2000. Organizational aesthetics, reflective practice, first person research, authentic leadership.
B. Tulu, Professor, WPI Business School. Ph.D., Claremont Graduate University, 2006. Design and development health information technologies.
B. Vernescu, Professor, Mathematical Sciences. Ph.D., Institute of Mathematics, Bucharest, Romania, 1989. Partial differential equations, homogenization, calculus of variation.
H. Walker, Professor Emeritus, Mathematical Sciences. Ph.D., New York University, 1970. Computational mathematics, numerical methods for systems of linear and nonlinear equations.
S. L. Weekes, Professor, Mathematical Sciences. Ph.D., University of Michigan, 1995. Numerical methods, mathematical modeling, dynamic materials.
J. R. Whitehill, Assistant Professor, Computer Science Department. Ph.D., University of California, San Diego, 2012. Machine learning, crowdsourcing, automated teaching, human behavior recognition.
E. V. Wilson, Associate Teaching Professor, WPI Business School. Ph.D., University of Colorado-Boulder, 1995. E-health, computer mediated communications.
Z. Wu, Associate Professor, Mathematical Sciences. Ph.D., Yale University, 2009. Big data statistical analytics, bioinformatics.
Z. Zhang, Associate Professor; Ph.D., Brown University, 2014, Shanghai University, 2011.Numerical analysis, scientific computing, computational and applied mathematics, uncertainty qualification.
J. Zhu, Professor, WPI Business School. Ph.D., University of - Massachusetts, 1998. Performance evaluation and benchmarking, sustainable design and performance.

Faculty Research

Our faculty work in many areas related to Data Science, including in:

- Big data and high performance analytics
- Bioinformatics and genomic data bases
- Business intelligence and predictive analytics
- Cybersecurity analytics
- Cryptography and data security
- Educational data mining
- Financial decision making
- Healthcare data analytics
- Internet big data analysis
- Large-scale data management and infrastructures
- Machine learning, data mining & knowledge discovery
- Signal processing and information theory
- Social media analytics
- Statistical learning
- Visual and numerical analysis of large data sets

Program of Study

The WPI Data Science (DS) program offers graduate studies toward an M.S., B.S./M.S. and Ph.D. Degree as well as a Certificate in Data Science. This Data Science program educates professionals, Data Scientists, with interdisciplinary skills in analytics, computing, statistics, and business intelligence. Key skills include the ability to recognize problems that can be solved with data analytics, apply the appropriate technologies on a given data problem, and communicate those solutions effectively to relevant stakeholders. Our faculty, together with our industrial partners, provide students with the resources and opportunities to engage in practical, purpose-driven projects, formal course work, and mentored interdisciplinary research work. This Data Science program requires advanced, in-depth course work in business, innovation, data analytics, computing, and statistical foundations. The program is designed to provide focused study in an area of interest to the student, ranging from general data analytics, computing, mathematical analytics, and business analytics, to specialized concentrations in financial analytics, healthcare analytics, biomedical analytics, analytics for sustain- ability, and learning sciences, among others. Due to their increased interdisciplinary perspective, our graduates will have a clear competitive advantage over professionals who are trained in a single discipline, such as business administration, statistics, or computer science, and who are seeking to work in the data analytic industry. As such, they will be poised to successfully become leaders in Data Science, helping to formalize and realize its vision.
The graduate degree program in Data Science is designed to produce the future generation of data scientists who are proficient in their ability to:

- Assess the suitability of, apply, and advance state-of-art data analytics tools and methods from data analysis, statistics, data mining, data management, computational thinking, big data algorithms, and visualization to bring about transformative solutions to important real-world problems across a number of domains.
- Bring to bear their integrative, interdisciplinary knowledge and skills in the core disciplines central to Data Science (Computing, Statistics, and Business) to understand and then to explain analytics results and their applicability and validity to those responsible for solving real-world problems.
- Serve as visionary leaders and project managers in data analytics, with the technical, and professional

knowledge and skills needed for the current and future career demands of data scientists working on impactful projects.

Admissions Requirements

Students applying to the graduate degree program in Data Science (DS) are expected to have a bachelor's degree with a strong quantitative and computational background including coursework in programming, data structures, algorithms, univariate and multivariate calculus, linear algebra and introductory statistics. Students with a bachelor's degrees in computer science, mathematics, business, engineering and quantitative sciences would typically qualify if they meet the above background requirements.A strong applicant who is missing necessary data science background may be admitted with the expectation that he or she will take the Data Science transition courses as needed, which include CS5007 if missing programming and algorithms background, and DS517 if missing statistics background. Credits for these transition courses count towards the M.S. degree. Students applying to the Certificate in Data Science are expected to meet the same qualifications described above.

Affiliated Departments and Programs

This is a joint program administered by the Computer Science Department, Mathematical Sciences Department, and the WPI Business School. Closely affiliated departments also include Social Science and Policy Studies Department, Learning Sciences and Technologies Program, Bioinformatics and Computational Biology Program, and the Electrical and Computer Engineering Department. Data Science faculty are comprised of faculty interested in Data Science graduate education and research and who hold advanced degrees.

Industrial Relationships

In collaboration with WPI's Corporate and Professional Education, the Data Science faculty work with industrial, government and academic partners who serve on an Advisory Board to help shape the WPI Data Science program and its offerings to assure its continued relevancy. In addition, these Advisory Board members provide input on industrial hiring needs, offer projects and internships to Data Science students, and serve as employers of our graduates.

B.S./M.S. in Data Science

The requirements for the proposed M.S. in Data Science are structured so that undergraduate student would be able to pursue a five-year Bachelor's/Master's program, in which the Bachelor's degree is awarded in any major offered at WPI and the Master's degree is awarded in Data Science. Students enrolled in the B.S./M.S. program must satisfy all the program requirements of their respective B.S. degree and all the program requirements of the M.S. degree in Data Science. For students who will earn the Data Science B.S. degree at WPI, the "Integrative Data Science" core area requirement is waived. Instead, the students can earn the corresponding 3 credits by taking any of the data science courses listed in the graduate catalog, including DS 501.

WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelor's/Master's program. This overlap can be achieved through the following mechanisms. Students may double-count courses towards both their undergraduate and graduate degrees whose credit hours total no more than 40 percent of the 30 credit hours required for the M.S. degree in Data Science, and that meet all other requirements for each degree. These courses can include graduate courses as well as certain undergraduate 4000-level course as long as the undergraduate course is acceptable in place of a corresponding graduate course that satisfies a Data Science M.S. requirement.

In consultation with the academic advisor, the student prepares a Plan of Study outlining the selections chosen to satisfy the B.S./M.S. degree requirements, including the courses that will be double-counted. This Plan of Study must then be approved by the Data Science Program.

As a university wide rule, the B.S./M.S. double counting credits can be applied for only while the student is an undergraduate student.

Double Counting Credits From 4000-Level Courses

For the following 4000-Level courses, two graduate credits will be earned towards the B.S./M.S. degree if the student achieves grade B or higher, or otherwise with the instructor's approval. In addition, faculty may offer, at their discretion, an additional 1/6 undergraduate unit, or equivalently a 1 graduate credit, for completing additional work in the course. To obtain this additional credit, the student must register for 1/6 undergraduate unit of independent study at the 4000-level or a 1 graduate credit independent study at the 500-level, with permission from the instructor.

Courses from Computer Science
CS 4120 Analysis of Algorithms
CS 4341 Introduction to Artificial Intelligence
CS 4342 Machine Learning
CS 4432 Database Systems II
CS 4445 Data Mining and Knowledge Discovery in Databases
CS 4518 Mobile and Ubiquitous Computing
CS 4802 BioVisualization
CS 4803 Biological and Biomedical Database Mining
Courses from Mathematical Sciences
MA 4235 Mathematical Optimization
MA 4603 Statistical Methods in Genetics and Bioinformatics
MA 4631 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II
DS 4635/MA 4635 Data Analytics and Statistical Learning

Other 4000-level courses not listed above, including 4000-level independent study courses, require a petition and approval from the Data Science Graduate Committee before they can double-count for the B.S./M.S. degree.

Restricted Undergraduate and Graduate Course Pairs

Some undergraduate and graduate courses have significant overlap in their content. The following table lists these courses.
A student can receive credit towards their M.S. degree for at most one of the two courses in any row of this table.

Courses from Computer Science

Undergraduate Course	Graduate Course
CS 4341 Introduction to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4342 Machine Learning	CS 539 Machine Learning
CS 4432 Database Systems II	CS 542 Database Management Systems
CS 4445 Data Mining and Knowledge Discovery	CS 548 Knowledge Discovery and Data Mining
CS 4518 Mobile and Ubiquitous Computing	CS 528 Mobile and Ubiquitous Computing
CS 4802 Biovisualization	CS 592 Biovisualization
CS 4803 Biological and Biomedical Database Mining	CS 583 Biological and Biomedical Database Mining

Courses from Mathematical Sciences

Undergraduate Course	Graduate Course
MA 4631 Probability and Mathematical Statistics I	MA 540 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II	MA 541 Probability and Mathematical Statistics II
DS 4635/MA 4635 Data Analytics and Statistical Learning	MA 543/DS 502 Statistical Methods for Data Science

Satisfying Data Science Core Areas

B.S./M.S. students can use the B.S./M.S. credits to satisfy a core area requirement if any of the following conditions is met: (1) The undergraduate course under consideration, either used to earn 2 or 3 graduate credits, must appear in one of the tables above, and the corresponding graduate course must satisfy the core area requirement. (2) The undergraduate course or independent study/project work is not in the tables listed above but it is deemed to satisfy the core area. This requires submitting a petition along with a detailed course description and syllabus to the Data Science Program for final decision.

Type: B.S./M.S.

Certificate in Data Science

The certificate program in Data Science prepares students to harness, analyze and interpret data in real-world applications. The certificate consists of 12 credits that must satisfy the following criteria: (1) DS 501 is mandatory, (2) two additional courses must be from the Data Science core courses listed in the graduate catalog, and (3) the remaining credits can be earned from any Data Science elective course(s) listed in the graduate catalog or otherwise approved by the program.

The certificate courses may be subsequently applied to a degree program at WPI, including the M.S. degree in Data Science, providing the courses meet the requirements of that degree program.

Students who have completed or are currently enrolled in a graduate degree at WPI (other than Data Science) can double count graduate credits from their graduate degree to meet up to one-third of the graduate credits for a (subsequent) Graduate Certificate in Data Science.

Type: Certificate

M.S. in Data Science

Students pursuing the M.S. degree in Data Science must complete a minimum of 30 credits of relevant work at the graduate level. These 30 credits must include the core coursework requirements in Data Science (see below) and either a 3-credit Graduate Qualifying Project (GQP) or a 9-credit M.S. thesis. These M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively and also students who are pursuing a combined B.S./M.S. degree.

Upon acceptance to the M.S. program, students will be assigned an academic advisor who will work with the student to correctly prepare a Plan of Study. This Plan of Study must then be approved by the Data Science Program Review Board.

Type: Master of Science

GQP Track

Graduate Qualifying Project

Item #	Title	Credits
DS 598	Graduate Qualifying Project	3

Required Core Areas

Item #	Title	Credits
	Integrative Data Science	3
	Mathematical Analytics	3
	Data Access & Management	3
	Data Analytics and Mining	3
	Business Intelligence & Case Studies	3

Concentration and Electives

Item #	Title	Credits
	Electives (12 credits)	12

M.S. Thesis Track

Item #	Title	Credits
DS 599	Master's Thesis in Data Science	9
Item #	**Title**	**Credits**
	Integrative Data Science	3
	Mathematical Analytics	3
	Data Access & Management	3
	Data Analytics and Mining	3
	Business Intelligence & Case Studies	3

Concentration and Electives

Item #	Title	Credits
	Electives (6 credits)	6

Core Data Science Coursework Requirement (15 credits)

Students in the M.S. program must take both courses in the Integrative Data Science category and one (1) course from each of the other core Data Science categories listed below:

Integrative Data Science (required):

Item #	Title	Credits
DS 501	Introduction to Data Science	3

Mathematical Analytics (Select one):

Item #	Title	Credits
DS 502/MA 543	Statistical Methods for Data Science	3
MA 542	Regression Analysis	3
MA 554	Applied Multivariate Analysis	3

Data Access and Management (Select one):

Item #	Title	Credits
CS 542	Database Management Systems	3
MIS 571	Database Applications Design and Development	3
CS 561	Advanced Topics in Database Systems	3
CS 585/DS 503	Big Data Management	3

Data Analytics and Mining (Select one):

Item #	Title	Credits
CS 548	Knowledge Discovery and Data Mining	3
CS 539	Machine Learning	3
DS/CS 541	Deep Learning	3
CS 586/DS 504	Big Data Analytics	3

Business Intelligence and Case Studies (Select one):

Item #	Title	Credits
MIS 584	Business Intelligence	3
MIS 587	Business Applications in Machine Learning	3
MKT 568	Data Mining Business Applications	3

If a student has completed a B.S. degree in Data Science at WPI, then the "Integrative Data Science" core area requirement is waived. Instead, the student can earn the corresponding 3 credits by taking any of the data science courses listed in the graduate catalog, including DS 501.

If a student does not have prior background in a particular core category, then it is advised that the student take the course with an asterisk * in the title within that category. If two or more courses have an asterisk *, then the student may select either of these courses based on their personal interest and background. Students must take at least 1 course in each of these core areas, but are encouraged to take several. Additional courses taken in a core category will count as electives and/or concentration courses as described below.

Graduate Qualifying Project GQP or M.S. Thesis

A student in the M.S. program must complete one of the following two options:

- **3-credit Graduate Qualifying Project**. (DS 598) This project is most commonly done in teams, and will provide a capstone experience in applying data science skills to a real-world problem. It will be carried out in cooperation with a sponsor or an industrial partner, and must be approved and overseen by a faculty member affiliated with the Data Science Program. The graduate qualifying project is typically taken for 3 graduate credits. With permission by the instructor, a student can take the course a second time for additional credit, up to a total of 6 graduate credits. This means that the student could take two offerings of the course concurrently in one semester or could register for three credits in one semester and another three credits in a subsequent semester. A student that follows this practice-oriented project option must gain sufficient Data Science depth by selecting at least 2 courses beyond the required Data Science core courses from among the electives below within the same area of concentration.

- **9-credit Master's Thesis.** (DS 599) A thesis in the Data Science Program consists of a research or development project worth a minimum of 9 graduate credit hours. Students interested in research, and in particular those who are considering a Ph.D. in a related area, are encouraged to select the M.S. thesis option. Any affiliated DS faculty may serve as the thesis advisor. If the advisor is not a tenure-track faculty at WPI, then a DS affiliated tenure-track faculty member must serve as the thesis co-advisor. A thesis proposal must be approved by both the DS Program Review Board and the student's advisor before the student can register for more than three thesis credits. The student must then satisfactorily complete a written thesis and present the results to the DS faculty in a public presentation.

Electives and Areas of Concentration (6-12 credits)

A student seeking an M.S. in Data Science program must take course work from the Program electives listed below in order to satisfy the remainder of the 30 credit requirement. An elective may be any of these graduate-level courses, with the restriction that no more than 16 credits of the 30-credit Data Science degree program may be courses offered by the School of Business.

While the core areas ensure that students have adequate coverage of essential Data Science knowledge and skills, the wide variety of electives enable students to tailor their Data Science degree program to domain and technique areas of personal interest. Students are expected to select elective course work to produce a consistent program of study. While the core coursework requirements provide the needed breadth in Data Science core categories, students will gain depth in one or several concentrations by choosing appropriate electives from the list of pre-approved courses relevant to data science.

Other courses beyond the pre-approved Program electives may be chosen as electives, but only with prior approval by the DS Program Review Board, and if consistent with the student's Plan of Study. For example, students might choose to concentrate their data science expertise on areas of physics, engineering, or sciences, not captured in the electives below. Independent study and directed research courses also require prior approval by the DS Program Review Board.

List of Program Elective Courses:

Relevant Business Graduate Courses (a maximum of 12 graduate credits of School of Business coursework may count toward the M.S. in Data Science):

BUS 500. Business Law, Ethics and Social Responsibility
FIN 500. Financial Management
FIN 503. Financial Decision Making for Value Creation
MIS 500. Innovating with Information Systems
MIS 571. Database Applications Development
MIS 573. Systems Design and Development
MIS 576. Project Management
MIS 581. Policy and Strategy for Information Technology and Analytics
MIS 583. User Experience Applications
MIS 584. Business Intelligence
MIS 585. User Experience Design
MIS 587. Business Applications in Machine Learning
MKT 568. Data Mining Business Applications
OBC 505. Teaming and Organizing for Innovation
OBC 506. Leadership
OIE 501. Operations Management
OIE 542. Risk Management and Decision Analysis
OIE 544. Supply Chain Analysis and Design
OIE 552. Modeling and Optimizing Processes
OIE 559. Advanced Prescriptive Analytics: From Data to Impact

Relevant Computer Science Graduate Courses:

CS 5007. Introduction to Applications of Computer Science with Data Structures and Algorithms
CS 5084. Introduction to Algorithms: Design and Analysis
CS 504. Analysis of Computations and Systems
CS 509. Design of Software Systems
CS 525. Topics in Computer Science (with prior approval of the Program Review Committee to determine relevancy)
CS 528. Mobile and Ubiquitous Computing
CS 534. Artificial Intelligence
CS 536. Programming Language Design
CS 539. Machine Learning
CS 541/DS 541. Deep Learning
CS 542. Database Management Systems
CS 545. Digital Image Processing
CS 546. Human-Computer Interaction
CS 547/DS 547. Information Retrieval
CS 548. Knowledge Discovery and Data Mining
CS 549. Computer Vision
CS 561. Advanced Topics in Database Systems
CS 573. Data Visualization
CS 584. Algorithms: Design and Analysis
CS 585/DS 503. Big Data Management
CS 586/DS 504. Big Data Analytics

Note: Students may not receive credit for both CS 5084 and CS 584

Relevant Mathematical Sciences Graduate Courses:

MA 511. Applied Statistics for Engineers and Scientists
MA 517/DS 517. Mathematical Foundations for Data Science
MA 529. Stochastic Processes
MA 540. Probability and Mathematical Statistics I
MA 541. Probability and Mathematical Statistics II
MA 542. Regression Analysis
MA 543/DS 502. Statistical Methods for Data Science
MA 546. Design and Analysis of Experiments
MA 547. Design and Analysis of Observational and Sampling Studies
MA 549. Analysis of Lifetime Data
MA 550. Time Series Analysis
MA 552. Distribution-Free and Robust Statistical Methods
MA 554. Applied Multivariate Analysis
MA 556. Applied Bayesian Statistics

Relevant Learning Sciences and Technology Program Graduate Courses:

CS 565. User Modeling
CS 566. Graphical Models For Reasoning Under Uncertainty
CS 567. Empirical Methods For Human-Centered Computing

PSY 505. Advanced Methods and Analysis for the Learning and Social Sciences

Relevant Bioinformatics and Computational Biology Program Courses:

BCB 501. Bioinformatics

BCB 502/CS 582. Biovisualization

BCB 503/CS 583. Biological and Biomedical Database Mining

BCB 504/MA 584. Statistical Methods in Genetics and Bioinformatics

Relevant Biomedical Engineering Courses:

BME 595. Special Topics: Machine Learning for Biomedical Informatics

Relevant Electrical and Computer Engineering Department Courses:

ECE 502. Analysis of Probabilistic Signals And Systems

ECE 503. Digital Signal Processing

ECE 504. Analysis of Deterministic Signals And Systems

ECE 578/ CS 578. Cryptography and Data Security

ECE 630. Advanced Topics in Signal Processing

ECE 673/CS 673. Advanced Cryptography

ECE 5311. Information Theory and Coding

Other Relevant Graduate Courses and Concentration Areas: Beyond courses in the three core disciplines of computer science, business, and statistics, relevant graduate courses in other potential areas of concentration, such as Finance, Manufacturing, Healthcare, National Security, Engineering, Fraud Detection, Science, Smart Grid Management, Sustainability and the like, may be added in the future to the above list of pre-approved Program electives.

Specializations of the Data Science Degree:

Specializations of the Data Science degree in targeted areas of high societal impact ranging from Health Care to National Security may be designed in the future. We expect these specializations to naturally fit into the flexible structure of the Data Science degree framework.

Ph.D. in Data Science

Students are advised to contact the program for detailed rules, as there are program guidelines, in addition to the university's requirements, for the Ph.D. degree.

Upon admission, the student is assigned an academic advisor and together they design a Plan of Study during the first semester of the student's Ph.D. program. A Ph.D. student without a prior M.S. degree is required to take the M.S. thesis Option to engage in research early on.
The student must satisfy the Ph.D. Qualification Requirement, which include the core breadth and core depth competency requirements. The Core breadth competency includes at least one course in each of the core Data Science areas, while the latter implies that the student must take at least two courses in two of these core areas. Only courses in which the student has obtained an A or a B grade can be used to satisfy these two competency requirements; with 4 of these 7 courses having to be an A letter grade.

In addition the Ph.D. Qualification requirement also includes the Qualifying Examination. These qualification requirements are described in the Graduate Regulations on the Data Science program website https://www.wpi.edu/academics/departments/data-science.

Upon successful completion of the Ph.D. qualifying requirement, the student be- comes a Data Science Ph.D. candidate. The student's Dissertation Committee must be formed within the first year of candidacy. With approval from the Data Science Steering Committee, the student selects a research advisor. Also with approval from the Data Science Steering Committee, the student and research advisor select three additional members, at least one of whom must be from a core data science department different than that of the research advisor and at least one must be from outside of WPI. The Dissertation Committee will be responsible for approving the dissertation proposal and the final dissertation manuscript.

The Ph.D. degree requirements consist of a coursework component and a research component, which together must total at least 60 credit hours beyond the master's degree. The coursework component consists of at least 30 coursework credits, as specified on the Data Science program website https://www.wpi.edu/academics/departments/data-science.

The student may also enroll for research credits, but is only allowed up to 18 research credits prior to the acceptance of the written dissertation proposal by her Dissertation Committee. With approval of the Dissertation Committee, the student applies for and takes the dissertation proposal examination, usually within one year of the Ph.D. candidacy.

The Ph.D. research component consists of at least 30 credits (including any research credits earned prior to the acceptance of the dissertation proposal and excluding any research credits applied toward a master's degree) leading to a dissertation and a public defense, which must be approved by the student's Dissertation Committee.

Type: Ph.D.

Electrical and Computer Engineering

Faculty and Research Interests

D. R. Brown, Professor and Interim Department Head; Ph.D., Cornell University. Signal processing, synchronization, control systems, inference, and wireless networks.
M. Amissah, Assistant Teaching Professor; Ph.D., Old Dominion University. Research focus: Model Based Systems Engineering, Systems Architecture, Complexity Science.
S. V. Bhada, Assistant Professor, Ph.D., University of Alabama at Huntsville. Modeling and Analysis of Policy Content and Systems Engineering.
E. A. Clancy, Professor; Ph.D., MIT. Biomedical signal processing and modeling, biomedical instrumentation.
A. Clark, Assistant Professor; Ph.D., University of Washington. Security, control of cyber-physical systems.
Y. Doroz, Assistant Teaching Professor; Ph.D., Worcester Polytechnic Institute. Blockchains and cryptocurrencies, post-quantum cryptography, fully homomorphic encryption schemes and applications, accelerating Cryptographic applications using hardware/software co-designs.
F. Ganji, Assistant Professor; Ph.D. Technical University of Berlin (Germany). Security, machine learning, hardware security, post-quantum cryptography.
U. Guler, Assistant Professor, Ph.D., Bogozici University, Turkey. Smart Health Applications, Implantables and Wearables, Sensor Interfaces, Neural Interfaces, RF-Energy Harvesting, Wireless Power and Data Transfer, Power Management IC, Biomedical Security, and, Low Power Analog/Mixed Signal IC Design.
X. Huang, Professor; Ph.D., Virginia Tech. Autonomous vehicles; computer vision; machine learning; FPGA and VLSI design; internet of things.
R. Ludwig, Professor and Associate Department Head; Ph .D., Colorado State University. Design of RF coils for magnetic resonance imaging; amplifier design; nondestructive material evaluation.
S. N. Makarov, Professor; Ph.D., Dr.Sci, St. Petersburg State University (Russian Federation). Bioelectromagnetics, Electromagnetic therapeutic devices, Antennas and electromagnetic sensors. Human body CAD models.
J. A. McNeill, Professor and Interim Dean of Engineering; Ph.D., Boston University. Analog IC design; high-speed imaging; mixed-signal circuit characterization.
M. Mughal, Assistant Teaching Professor; Ph.D., Arkansas State University. Scalable synthesis of nanostructured thin film materials for solar applications, prediction of solar variability for better grid integration.
K. Mus, Assistant Teaching Professor; Ph.D., Middle East Technical University, Turkey. Cybersecurity, post-quantum cryptography, fault attacks.
K. Pahlavan, Professor; Ph.D., Worcester Polytechnic Institute. Wireless networks.
P. Schaumont, Professor; Ph.D., University of California at Los Angeles. Hardware security; reverse engineering; embedded systems; hardware-software codesign; digital IC design.
B. Sunar, Professor; Ph.D., Oregon State University . Cybersecurity; applied cryptography; high-speed computing.
S. Tajik, Assistant Professor; Ph.D., Technical University of Berlin, Germany. Non-invasive and semi-invasive side-channel analysis, Physically Unclonable Functions (PUFs), machine learning, FPGA security, and designing anti-tamper mechanisms against physical attacks
E. Uzunovic, Assistant Teaching Professor; Ph.D., University of Waterloo, Canada. High voltage, direct current power transmission, advanced power distribution, power electronics including smart inverters.
A. M. Wyglinski, Professor and Associate Dean of Graduate Studies; Ph.D., McGill University . Cognitive radio, 4G/5G/6G/Next-G, spectrum sensing and co-existence, machine learning-based data transmission techniques, GPS and satellite communications, connected and autonomous vehicles, software-defined radio prototyping and test-beds, millimeter wave transmission, rural broadband and the Digital Divide.
Z. Zhang, Assistant Professor; Ph.D., Oxford Brookes University, UK. Computer vision and machine learning, especially in object recognition/detection, data-efficient learning.

Emeritus

K. A. Clements, D. Cyganski, J. S. Demetry, A.E. Emanuel, F. J. Looft, J. A. Orr, P. C. Pedersen

Affiliated Faculty

E. Agu (CS), G. Fischer (ME), Jie Fu (RBE), C Furlong (ME), M. Gennert (CS), Y. Mendelson (BME), W. R. Michalson (RBE), L. Ramdas Ram-Mohan (PH), J. Sullivan (ME)

Programs of Study

The Electrical and Computer Engineering (ECE) Department offers programs leading to M.Eng., M.S. and Ph.D. degrees in electrical and computer engineering, an M.Eng. degree in power systems engineering (PSE), as well as graduate and advanced certificates. The following general areas of specialization are available to help students structure their graduate courses: Smart Connected Systems, Integrated System Design, Cybersecurity, Power Systems.

The M.S. ECE degree is designed to provide an individual with advanced knowledge in one or more electrical and computer engineering areas via successful completion of at least 21 credits of WPI ECE graduate courses (including M.S. thesis credit), combined with up to 9 credits of coursework from computer science, mathematics, physics and other engineering disciplines.

The M.Eng. ECE and M.Eng. PSE degrees are tailored for individuals seeking an industrial career path. Similar to the M.S. degree, the M.Eng. degree requires the successful completion of at least 21 credits of WPI ECE graduate courses (specific course requirements for the M.S. ECE and M.S. PSE degrees are discussed below). In contrast to the M.S. degree, the M.Eng. degree allows up to 9 credits on non-ECE courses to be chosen as management courses and does not include a thesis option.

Admission Requirements

Master's Program

Students with a B.S. degree in electrical engineering or electrical and computer engineering may submit an application for admission to the Master's program. There are three degree options in the Master's program: An M.S. in Electrical and Computer Engineering, an M.Eng. in Electrical and Computer Engineering, and an M.Eng. in Power Systems Engineering. Admission to the Master's program will be based on a review of the application and associated references.

Applicants without a B.S. degree in electrical engineering or electrical and computer engineering, but who hold a B.S. degree in mathematics, computer engineering, physics or another engineering discipline, may also apply for admission to the Master's program in the Electrical and Computer Engineering Department. If admitted, the applicant will be provided with required courses necessary to reach a background equivalent to the B.S. degree in electrical engineering or electrical and computer engineering, which will depend on the applicant's specific background.

Applicants with the bachelor of technology or the bachelor of engineering technology degree must typically complete about 1-1/2 years of undergraduate study in electrical engineering before they can be admitted to the graduate program. If admitted, the applicant will be provided with required courses necessary to reach a background equivalent to the B.S. degree in electrical engineering or electrical and computer engineering, which will depend on the applicant's specific background.

Ph.D. Program

Students with a Master's degree in electrical and computer engineering may apply for the doctoral program of study. Admission to the Ph.D. program will be based on a review of the application and associated references. Students with a Bachelor of Science degree in electrical and computer engineering may also apply to the Ph.D. program. Students with a strong background in areas other than Electrical and Computer Engineering will also be considered for admission into the Ph.D. program. If admitted (based on review of the application and associated references), the applicant may be approved for direct admission to the Ph.D. program, or to an M.S.-Ph.D. program sequence. Applicants possessing and M.S. degree in electrical and computer engineering from WPI that have not been directly admitted to the Ph.D. program are still required to submit an application and associated references for consideration, with the exception of GRE scores, TOEFL scores, and the application fee.

Certificate Requirements

The ECE Department offers advanced certificate and graduate certificate programs. Please visit https://www.wpi.edu/academics/study/electrical-computer-engineering-certificates

Degree Requirements

There are three degree options within the Master's program in the Electrical and Computer Engineering Department: A Master of Engineering in Electrical and Computer Engineering (M.Eng. ECE), a Master of Science in Electrical and Computer Engineering (M.S. ECE), and a Master of Engineering in Power Systems Engineering (M.Eng. PSE).

Program of Study

Each student must submit a program of study for approval by the student's advisor, the ECE Department Graduate Program Committee and the ECE Department Head. To ensure that the Program of Study is acceptable, students should, in consultation with their advisor, submit it to the ECE Department Graduate Secretary prior to the end of the semester following admission into the graduate program. Students must obtain prior approval from the ECE Department Graduate Program Committee for the substitution of courses in other disciplines as part of their academic program.

All full-time students in the Master's degree program (with the exception of B.S./M.S. students as noted below) are required to attend and pass the two graduate seminar courses, ECE 596A (fall semester) and ECE 596B (spring semester). See course listings for details.

Thesis Option

Students pursuing an M.S. ECE degree that are financially supported by the department in the form of teaching assistantship, research assistantship, or fellowship are required to complete a thesis. The thesis option is not available for students pursuing an M.Eng. ECE or M.Eng. PSE degree. M.S. thesis research involves 9 credit hours of work, registered under the designation ECE 599, normally spread over at least one academic year. For students completing the M.S. thesis as part of their degree requirements, a thesis committee will be set up during the first semester of thesis work. This committee will be selected by the student in consultation with the major advisor and will consist of the thesis advisor (who must be a full-time WPI ECE faculty member) and at least two other faculty members whose expertise will aid the student's research program. An oral presentation before the Thesis Committee and a general audience is required. In addition, all WPI thesis regulations must be followed.

Non-Thesis Option

Although the thesis is optional for M.S. ECE students not financially supported by the department, and there is no thesis option available for M.Eng. ECE or M.Eng. PSE students, all M.Eng. and M.S. students are encouraged to include a research component in their graduate program. A directed research project, registered under the designation ECE 598, involves a minimum of 3 credit hours of work under the supervision of a faculty member. The task is limited to a well-defined goal. Note that the Graduate Program committee will not allow credit received under the thesis designation (ECE 599) to be applied toward an M.Eng. ECE degree, M.Eng. PSE degree, or non-thesis M.S. ECE degree.

Transfer Credit

Students may petition to transfer a maximum of 15 graduate semester credits, with a grade of B or better, after they have enrolled in the degree program. This may be made up of a combination of up to 9 credits from the WPI ECE graduate courses taken prior to formal admission and up to 9 credits from other academic institutions. Transfer credit will not be allowed for undergraduate level courses taken at other institutions. In general, transfer credit will not be allowed for any WPI undergraduate courses used to fulfill undergraduate degree requirements; however note that there are exceptions in the case of students enrolled in the B.S./M.S. program.

Electrical and Computer Engineering Research Laboratories/Centers

Analog/Mixed Signal Microelectronics Laboratory

Prof. McNeill

The Analog and Mixed Signal Microelectronics Laboratory focuses on the continuation of research in self-calibrating analog to-digital converter architectures and low-jitter clock generation; funded by NSF, Allegro Microsystems, and Analog Devices. www.wpi.edu/+ECE

Bioelectromagnetics & Antenna Laboratory

Prof. Makarov/Prof. Noetscher

The Laboratory develops modeling and hardware design of various electronic systems and devices for biomedical (diagnostic and therapeutic) and wireless applications. Center for Advanced Integrated Radio Navigation (CAIRN)

Prof. Michalson

The Center for Advanced, Integrated, Radio Navigation (CAIRN) mission is the development of radio systems that integrate communications and navigation functions. Basic research into radio design (analog and digital), wireless ad hoc networking and positioning is performed for both indoor and outdoor radio environments. The laboratory develops, designs, implements, and field-tests a variety of radio and navigation systems. Housed within the laboratory is the Public Safety Integration Center, which focuses on the development and deployment of communications, information, and navigation technologies for public safety applications. Representative projects: Radio systems for indoor positioning, Digital radios for public safety systems, Simulation of wireless ad hoc networks for public safety applications.
http://www.wpi.edu/academics/ece/cairn/index.html

Center for Wireless Information Networking Studies (CWINS)

Prof. Pahlavan

The mission of the Center for Wireless Information Network Studies is the analysis of wideband radio propagation for design and performance evaluation of wireless access and localization techniques. The current focus of research is on body area networking and in particular localization of wireless video capsule endoscope inside the small intestine. The past focus of the center were on indoor geolocation and Wi-Fi localization for application in smart devices and robots. The center was established in 1985 as the world's first research center for the design of wireless local area networks. More details on the center are available at www.cwins.wpi.edu.

Collective Intelligence and Bionic Robotics (CIBR) Lab

Prof. Fu (ECE) and Prof. Li (ME)

CIBR lab is a joint lab between ECE faculty Jie Fu and ME faculty Zhi Li, under the Robotics Engineering Program. Our research focus is to bring a joint force between control theory, machine learning and robotics to achieve two major objectives: First, by leveraging learning-based control design, we aim to develop algorithms to achieve provably safe, adaptive and robust performance in autonomous systems in the presence of uncertain and dynamical environment. Second, we aim to build the algorithmic foundation for bionic robotics that facilitates a seamless collaboration between human and robots, with applications to advanced manufacturing, health, and medical robotics.

Embedded Computer Laboratory

Prof. Huang

The mission of the Embedded Computing Lab is to solve important problems of embedded computer systems, including theories, architectures, circuits, and systems. Our current research is focused on ASIC, FPGA and SoC design for signal processing, wireless communications, error correction coding, reconfigurable computing, and computing acceleration. Our research goal is to create new architectures and circuit designs to facilitate high-speed information processing at minimum power consumption. http://computing.wpi.edu/

Laboratory for Sensory and Physiologic Signal Processing – L(SP)2

Prof. Clancy

The mission of the Laboratory for Sensory and Physiologic Signal Processing L(SP)2 is to employ signal processing, mathematical modeling, and other electrical and computer engineering skills to study applications involving electromyography (EMG — the electrical activity of skeletal muscle). Researchers are improving the detection and interpretation of EMG for such uses as the control of powered prosthetic limbs, restoration of gait after stroke or traumatic brain injury, musculoskeletal modeling, and clinical/scientific assessment of neurologic function. http://users.wpi.edu/~ted/

Renewable Energy Innovations Laboratory

Prof. Mahmoud

Our lab emphasizes all aspects of innovations in renewable energy systems for the conversion, delivery, and its use in electrical form. Our aim is to contribute in expanding the utilization of renewable energy resources in the world by addressing technical challenges impeding their utilization, including reducing their cost, and improving their overall efficiency, operation, control, integration and reliability. Our objective is also to commercialize and transfer our developed technologies to market. https://www.wpi.edu/people/member/yamahmoud

Center for Imaging and Sensing (CIS)

Prof. Ludwig

The lab has access to high-field and ultra high-field magnetic resonance imaging (MRI) systems for use in functional and anatomical imaging. Major research focuses on visualization of elastic vibrations in the female breast. A novel coil geometry was designed that proved more efficient at generating these strong gradients when compared with conventional coil technology. Research has resulted in the design of special-purpose radio frequency array coil systems for breast cancer diagnosis, bone density determination, and stroke. The lab has successfully tested its single-tuned and dual-tuned prototypes at various sites throughout the U.S. in clinical MRI systems. www.wpi.edu/+ECE

ICAS Lab

Prof. U. Guler

The research program of ICAS Lab. explores the designs of a range of biomedical devices from implantable devices to wearable devices that ensure device security, personal privacy, accurate bio-sensing, and reliable operation and proposes possible directions of study that tackle the fundamental challenges including; sustainable energy harvesting systems for continuous long-term health monitoring (how sustainable energy harvesting and its efficient storage and usage are possible for continuous long-term personal health monitoring), secure bio-implants and wearables (how the security of all these sensors associated with smart healthcare will be assured in terms of maintaining proper functionality of devices and protecting private information), and wireless sensor Interfaces for medical and general purpose IoTs (how accurate and reliable sensing interfaces will be able to receive very low-amplitude signals coming from various environments, such as inside the body). https://icaslab.org/

Secure Cyber-Physical Systems Lab

Prof. Clark

Cyber-Physical Systems (CPS) are comprised of tightly integrated cyber (sensing, communication, computation) and physical (actuation) components in applications including transportation, medicine, energy, and housing. The goal of our lab is to develop foundations for CPS with provable guarantees on safety, performance, and security, in the presence of dynamic environments, random faults and failures, and malicious attacks.

Signal Processing and Information Networking Laboratory (SPINLab)

Prof. Brown

SPINLab was established in 2002 to investigate fundamental and applied problems in signal processing, communication systems, and networking. Our current focus is on the development of network carrier synchronization schemes to facilitate distributed beamforming and space-time coded cooperative transmission. We are also working on techniques for optimal resource allocation in multiuser communication systems and the application of game-theoretic tools to analyze selfish behavior in cooperative communication systems. SPINLab offers research opportunities at both the graduate and undergraduate levels. For more details, please see the SPINLab Web page at http://spinlab.wpi.edu.

Vernam Laboratory

Profs. Ganji, Schaumont, Sunar, Tajik, Eisenbarth, Doroz, Martin (Mathematics), Mus

The mission of the Vernam Group is to address both short-term and long-term security problems spanning several disciplines. Group members are focused on developing new security technologies to ensure the safety of all facets of the communication and computation infrastructure bridging the gap between cutting edge research and solid engineering practices, thus, providing the perfect setting for the education of next generation security experts. http://v.wpi.edu/

Wireless Innovation Laboratory (WILab)

Prof. Wyglinski The Wireless Innovation Laboratory (WILab) conducts fundamental and applied research in wireless communication systems engineering and vehicular technology . Consisting of approximately 1000 sq ft of prime research space as well as state-of-the-art software tool and experimentation equipment, this facility focuses on devising new real-world solutions and the creation of new knowledge in the areas of cognitive radio, rural broadband and the Digital Divide, connected and autonomous vehicles, software-defined radio, GPS and satellite communications, 4G/5G/6G/Next-G, spectrum sensing and co-existence, machine learning-based data transmission techniques, and millimeter wave transmission. WILab has been extensively funded via numerous sponsors from both government and industry, including the National Science Foundation, Verizon, MIT Lincoln Laboratory, MathWorks, Office of Naval Research, Toyota InfoTechnology Center USA, and the MITRE Corporation. For more details, please see the WILab website at http://www.Wireless.WPI.edu.

B.S./M.S. in Electrical and Computer Engineering

A WPI student accepted into the B.S./M.S. program may use 12 credit hours of work for both the B.S. and M.S. degrees. Note that students will not be able to receive an M.Eng. ECE or M.Eng. PSE degree via this particular program. At least 6 credit hours must be from graduate courses (including graduate level independent study and special topics courses), and none may be lower than the 4000-level. No extra work is required in the 4000-level courses. A grade of B or better is required for any course to be counted toward both degrees. A student must define the 12 credit hours at the time of applying to the B.S./M.S. program. Applications will not be considered if they are submitted prior to the second half of the applicant's junior year. Ideally, applications (including recommendations) should be completed by the early part of the last term of the junior year.

At the start of Term A in the senior year, but no later than at the time of application, students are required to submit to the graduate coordinator of the Electrical and Computer Engineering Department a list of proposed courses to be taken as part of the M.S. degree program. A copy of the student's academic transcript (grade report) must be included with the application.

All students in the B.S./M.S. program in Electrical and Computer Engineering who have completed their B.S. degree must register for at least six credits per semester until they complete 30 credits toward their M.S. degree. If fewer than six credits are required to complete the M.S. degree, then the student must register for at least the number of credits required to complete the degree. If a student double counts a full 12 credits for both the M.S. and B.S. degrees, then the remaining 18 credits must be completed within 3 semesters of graduate work (1.5 years).

Students who double count less than 12 credits for both the M.S. and B.S. degree will be allowed an additional semester (2 years) to complete the degree.

All B.S./M.S. students are required to attend and pass one of the graduate seminar courses, either ECE 596A (fall semester) or ECE 596B (spring semester).
Students enrolled in the B.S./M.S. program in Electrical and Computer Engineering may petition for permission to use a single graduate course (3 credits maximum) taken at other institutions to satisfy ECE B.S./M.S. degree requirements. The course must be at the graduate level and the student must have earned a grade of B or better to be considered for transfer credit.

Type: B.S./M.S.

Certificates in Power Systems

These specialized programs raise professional competency levels of protection power systems engineers and focus on topics like the protection and control aspects of the power industry.

These certificates consist of 12-18 credits of graduate coursework.

https://www.wpi.edu/academics/online/study/power-systems-online-certificates

Type: Certificate

Master of Engineering in Electrical and Computer Engineering

ECE Students pursuing the M.Eng. ECE degree require 30 graduate credits in course work, independent study, or directed research. There is no thesis option for the M.Eng. ECE degree program. At least 21 of the 30 credits must be graduate level activity (designated 500-, 5000-, or 600-level) in the field of electrical and computer engineering (course prefix ECE) offered by WPI. The remaining credits may be either at the 4000 level (maximum of six credits) or at the graduate level in computer science (CS), data science (DS), physics (PH), engineering (BME, CHE, CE, ECE FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or from the School of Business (ACC, BUS, ETR, FIN, MIS, MKT, OBC, and OIE). The complete program must be approved by the student's advisor and the Graduate Program Committee.

Type: Master of Engineering

Master of Engineering in Power Systems Engineering

The M.Eng. PSE is primarily delivered to industry professionals at a variety of off-campus locations; students should contact the ECE office staff regarding course availability. Students pursuing the M.Eng. PSE degree require 30 graduate credits in course work, independent study, or directed research. There is no thesis option for the M.Eng. PSE degree program. At least 21 of the 30 credits must be graduate level activity in the field of electrical and computer engineering offered by WPI; of these 21 credits, at least 15 must be in the field of power system engineering (course prefix ECE with course numbers from 5500 through 5599). The remaining courses may be either at the 4000 level (maximum of six credits) or at the graduate level (designated as 500-, 5000-, or 600-level) in computer science (CS), data science (DS), physics (PH), engineering (BME, CHE, CE, ECE, FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or from the School of Business (ACC, BUS, ETR, FIN, MIS, MKT, OBC, and OIE).

Type: Master of Engineering

M.S. in Electrical and Computer Engineering

ECE Students pursuing the M.S. ECE degree may take either the non-thesis option, which requires 30 graduate credits in course work, independent study, or directed research, or the thesis option, with a total of 30 graduate credits including a 9-credit thesis. In either case, at least 21 of the 30 credits must be graduate level activity (designated 500-, 5000-, or 600-level) in the field of electrical and computer engineering (course prefix ECE) offered by WPI. The remaining credits may be either at the 4000 (maximum of six credits) or the 500 level in computer science (CS), data science (DS), physics (PH), engineering (BME, CHE, CE, ECE, FP, MFE, MTE, ME, RBE, and SYS) and/or mathematics (MA). The complete program must be approved by the student's advisor and the Graduate Program Committee.

Type: Master of Science

Ph.D. in Electrical and Computer Engineering

The degree of doctor of philosophy is conferred on candidates in recognition of high scientific attainments and the ability to carry on original research. The following is a list of requirements for students intending to obtain a Ph.D. in Electrical and Computer Engineering.

Coursework and Residency Requirements

Students must complete 60 or more credits of graduate work beyond the credit required for the Master of Science degree in Electrical and Computer Engineering. Of the 60 credits, at least 30 credits must be research registered under the designation ECE 699. The doctoral student must also establish two minors in fields outside of electrical engineering. Physics, mathematics and/or computer science are usually recommended. Each student selects the minors in consultation with their Research Advisor. At least 6 credits of graduate work is required in each minor area. Courses with an ECE designation which are cross-listed in the course offerings of another department cannot be used toward fulfilling the requirements of a minor area.

All doctoral students are required to attend and pass two offerings of the ECE graduate seminar courses, ECE 596A (fall semester) and ECE 596B (spring semester). These students may either enroll in the same ECE graduate seminar course offered in two different semesters, or enroll in each of the two different ECE graduate seminar courses. Note that enrollment in these two courses is required regardless if the student has already successfully passed these courses and counted them towards the requirements of an M.S. degree or equivalent credit.

Full-time residency at WPI for at least one academic year is required while working toward a Ph.D. degree.

Research Advisor and Committee Selection

The doctoral student is required to select a Research Advisor and their Committee prior to scheduling their Diagnostic Examination. This will usually occur prior to the start of the student's second semester in the graduate program. The Research Advisor and all members of the Committee must hold doctoral degrees. The Research Advisor must be a full-time ECE faculty member. The Committee must consist of at least two faculty members, at least one of which must be an ECE faculty member and at least one of which must be from outside the ECE department or from outside WPI. The Committee is usually selected by the student in consultation with the Research Advisor. All members of the committee must be approved by the Research Advisor.

A completed Research Advisor and Committee Selection form must be filed with the ECE department prior to taking the Diagnostic Exam. A student may change their Research Advisor or members of their Committee by submitting a new Research Advisor and Committee Selection form to the Graduate Secretary. Changes to the student's Research Advisor after completion of the diagnostic examination must be approved by the ECE Graduate Program Committee. Changes to the student's Committee after completion of the area examination must be approved by the ECE Graduate Program Committee.

Diagnostic Examination Requirement

The doctoral student is required to complete the diagnostic examination requirement during the first year beyond the M.S. degree (or equivalent number of credits, for students admitted directly to the Ph.D. program) with a grade of Pass. The diagnostic examination is scheduled with the student's Research Advisor and Committee. Prior to scheduling the diagnostic examination, a student must have a completed Research Advisor and Committee Selection form on file in the ECE department.
The diagnostic examination is administered by the student's Research Advisor and at least one member of the Committee. Full participation of the Committee is recommended. At the discretion of the research advisor, additional faculty outside of the student's committee may also participate in the diagnostic examination. The diagnostic examination is intended to be an opportunity to evaluate the student's level of academic preparation and identify any shortcomings in the student's background upon entrance to the Ph.D. program. The format and duration of the diagnostic examination is at the discretion of the student's Research Advisor and Committee. The examination may be written or oral and may include questions to test the general background of the student as well as questions specific to the student's intended area of research.

The Research Advisor and Committee determine the outcome of the diagnostic examination (Pass, Repeat, or Fail) and any required remediation intended to address shortcomings identified in the student's background. A grade of Fail will result in dismissal from the graduate program. A grade of Repeat requires the student to reschedule and retake the diagnostic examination. A grade of Pass is expected to also include a summary of any prescribed remediation including, but not limited to, coursework, reading assignments, and/or independent study. Irrespective of outcome of the examination, a diagnostic examination completion form, signed by the student's Research Advisor and committee, must be filed with the ECE department upon completion of the examination.

Upon successful completion of the Diagnostic Examination, each doctoral student must submit a program of study to the ECE Department Graduate Secretary for approval by the student's research advisor, the ECE Department Graduate Program Committee and the ECE Department Head. The program of study should be completed in consultation with the student's research advisor and should include specific course work designed to address any shortcomings identified in the student's background during the Diagnostic Examination.

Area Examination Requirement

The doctoral student is required to pass the area examination before writing a dissertation. The area examination is intended to be an opportunity for the student's Advisor and Committee members to evaluate the suitability, scope, and novelty of the student's proposed dissertation topic. The format of the area examination is at the discretion of the student's Advisor and Committee but will typically include a presentation by the student describing the current state of their research field, their planned research activities, and the expected contributions of their work.

Students are eligible to take the area examination after they have successfully completed the diagnostic examination and have completed at least three semesters of coursework in the graduate program. All Ph.D. students are required to successfully complete the area examination prior to the completion of their seventh semester in the graduate program. Failure to successfully complete the area examination prior to the end of the student's seventh semester will be considered a failure to make satisfactory academic progress.

The Research Advisor and Committee determine the Pass/Fail outcome of the area examination. A grade of Fail will result in dismissal from the graduate program. Area examination completion forms must be signed by the student's Research Advisor and Committee Members and filed with the ECE department upon completion of the examination.

Dissertation Requirement

All Ph.D. students must complete and orally defend a dissertation prepared under the general supervision of their Research Advisor. The research described in the dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Research Advisor and Committee certify the quality and originality of the dissertation research, the satisfactory execution of the dissertation and the preparedness of the defense.

The Graduate Secretary must be notified of a student's defense at least seven days prior to the date of the defense, without exception. A student may not schedule a defense until at least three months after they have completed the area examination.

Type: Ph.D.

Fire Protection Engineering

Faculty

Core FPE Program Faculty

A. Simeoni, Professor and Department Head, Ph.D., University of Corsica; modeling, simulation and experiments of wildfires, heat and mass transfer, fire fighting and land management.
N. A. Dembsey, Professor; Ph.D., University of California at Berkeley; Fire properties of materials and protective clothing via bench-top scale experimentation; compartment fire dynamics via residential scale experimentation, evaluation, development and validation of compartment fire models, performance fire codes, engineering design tools, and engineering forensic tools.
K. A. Notarianni, Associate Professor; Ph.D., Carnegie Mellon University; Fire detection and suppression; high-bay fire protection; fire policy and risk; uncertainty; performance-based design; engineering tools for the fire service.
M. T. Puchovsky, Professor of Practice, Associate Department Head, Industry Liaison; design and analysis of fire protection systems, application of regulatory codes and standards, automatic sprinkler systems, fire pumps, water supplies, water and chemical-based suppression, detection and alarm, smoke control, means of egress, building construction, standardized product testing, performance-based design, litigation support.
A. Rangwala, Professor, Ph.D., University of California, San Diego; combustion, flame spread on solid fuels and compartment fire modeling, dust explosions, risk assessment of Liquefied Natural Gas (LNG) transport and storage, industrial fire protection.
J. L. Urban, Assistant Professor; Ph.D., University of California at Berkeley; Ignition, combustion, flame spread over solid fuels, wildland fire, thermal sciences,

computational modelling of fundamental fire phenomena, hazards of hot-work and welding, flame imaging and flow visualization.

Associated FPE Program Faculty

L. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology; Performance of structural members, elements, and systems at elevated temperatures; structural design for fire conditions; simplified or design office techniques for fire-structure interaction; relationship between building construction systems and fire service safety.
J. Liang, Associate Professor, Ph.D., Brown University, 2004. Nanostructured materials, material processing, material characterization.

Adjunct FPE Faculty

M. Hurley, Adjunct Instructor/Lecturer; Consulting, large unique building design, smoke control systems, detection and alarm, egress from fire.
W. Krein, Adjunct Assistant Professor; Fire Protection Engineering and School of Business; organizational behavior, entrepreneurship, corporate financial management, mergers and acquisitions, consulting, engineering economics, project management.
J. Tubbs, Adjunct Assistant Professor; Consulting, large unique building design, smoke control systems, detection and alarm, egress from fire.
C. Wood, Adjunct Associate Professor; Licensed attorney, fire protection engineering, expert witness testimony, fire modeling and dynamics. Fire investigation, failure analysis of fires and explosions.

FPE Emeritus

R. W. Fitzgerald, Professor Emeritus; Ph.D., University of Connecticut; structural aspects of fire safety, building analysis and design for fire safety, marine fire safety, building codes, real estate development, fire department operations, risk management.
D. A. Lucht, Director Emeritus; building codes and regulatory reform, building fire safety analysis and design, professional practice.
R. Zalosh; Professor Emeritus, Ph.D., Northeastern University; Fire and explosion hazards associated with flammable gases, liquids, and powders. Fire/explosion protection methods and systems designed to deal with these special hazards. Theoretical, experimental, and risk-based engineering tools for addressing these issues.

Research Interests

WPI is a recognized world leader in a wide range of topics in fire protection engineering and related areas. Research is directed toward both theoretical understandings and the development of practical engineering methods. WPI faculty and their students create new knowledge that informs and shapes regulatory policy, building design, product manufacturing, and product performance standards.

Specific capabilities and interests include: fire and material;, combustion and explosion protection; computer modeling; fire performance of structural systems; fire detection and suppression; fire and smoke dynamics; wildland and wildland-urban interface fires; regulatory policy, risk, and engineering framework; and firefighter safety and policy.

Programs of Study

The Department of Fire Protection Engineering serves as a crossroads for bringing together talents from many disciplines to focus on fire and explosion safety problems. The department features formal degree and certificate programs in fire protection engineering, continuing education for the practitioner, and research to uncover new knowledge about fire behavior and fire protection methods.

The fire protection engineering program at WPI adapts previous educational and employment experiences into a cohesive Plan of Study. Consequently, the program is designed to be flexible enough to meet specific and varying student educational objectives. Students can select combinations of major courses, non-major courses, thesis and project topics that will prepare them to proceed in the career directions they desire. The curriculum can be tailored to enhance knowledge and skill in the general practice of fire protection engineering, in fire protection engineering specialties (such as industrial, chemical, energy, design, or testing), or in the more theoretical and research-oriented sphere.

Practicing engineers or others already employed and wishing to advance their technical skills may enter the program as part-time students or take off-campus courses via WPI's Quality Online Courses (see page 8) The master's degree may be completed on a part-time basis in less than two years, depending on the number of courses taken each semester.

WPI offers both master's and doctoral degrees as well as the advanced certificate and graduate certificate in fire protection engineering.

WPI offers combined B.S./M.S. programs for students wishing to complete two degrees in a condensed time frame.

Admission Requirements

High school graduates applying for the Combined B.S./Master's Program must meet normal undergraduate admission criteria. Applicants for the master's or certificate programs should have a B.S. in engineering, engineering technology or the physical sciences. Applicants with no FPE work experience should submit a two-page essay articulating their interest in the field.

Students with science degrees and graduates of some engineering technology disciplines may be required to take selected undergraduate courses to round out their backgrounds.
GRE scores are required for all international students and all Ph.D. applicants.

Graduate Internships

A unique internship program is available to fire protection engineering students, allowing them to gain important clinical experiences in practical engineering and research environments. Students are able to earn income while maintaining their student status. Internships are generally full time for one year and provide the student a chance to try out various areas of practice, generate income, gain knowledge and experience, and make valuable lifetime contacts. No Graduate Credit is earned during an internship. A minimum of 9 graduate credits in FPE must be earned prior to participation in an internship. All Internships must be related to FPE.

Research Laboratories

Fire Science Laboratory

This brand new and exciting laboratory facility supports both fundamental studies and large scale engineering studies, experimentation in fire dynamics, combustion/explosion phenomena, detection, and fire and explosion suppression. The Fire Propagation Apparatus, cone calorimeter, infrared imaging system, phase doppler particle analyzer and room calorimeter are also available, with associated gas analysis and data acquisition systems, making this a truly unique awe-inspiring place to conduct research.
The wet lab area supports water-based fire suppression and demonstration projects.

Serving as both a teaching and research facility, the lab accommodates undergraduate projects as well as graduate students in fire protection engineering, mechanical engineering and related disciplines.

Fire Modeling Laboratory

The Fire Modeling Laboratory specializes in computer applications to fire protection engineering and research. Research activities include computational fluid dynamics modeling of building and vehicle fires, flame spread model development, and building egress modeling.

Combustion Laboratory

The WPI Combustion Lab supports studies of fundamental combustion properties as they relate to fire safety. Experimental set-ups are available for the study of self-heating of coal dust; flammable properties of gasoline containers; cross-correlation velocimetry and the laminar burning velocity of flammable dusts.

B.S./M.S. in Fire Protection Engineering

High school seniors and engineering students in their first three years can apply for this five-year program. This gives high school graduates and others the opportunity to complete the undergraduate degree in a selected field of engineering and the master's degree in fire protection engineering in five years. Holders of bachelor of science degrees in the traditional engineering fields and the master's degree in fire protection engineering enjoy extremely good versatility in the job market.

Type: B.S./M.S.

Certificate in Fire Protection Engineering

The graduate certificate program in Fire Protection Engineering provides qualified students with an opportunity to further their studies in an advanced field. A completed undergraduate degree in engineering or physical science is the preferred prerequisite for admission. Four courses are selected from a range of offerings in consultation with an academic advisor. Taken together, the courses form a cohesive theme. Options include but are not limited to: Core Concepts in Fire Protection Engineering, Industrial Applications, Hazard and Risk Assessment, Facility and Building Design, Advanced Protection Systems, and Fire Protection Management.

Type: Certificate

M.S. in Fire Protection Engineering

The M.S. program is a graduate level program in Fire Protection Engineering that is structured to be equally effective for full-time or part-time distance learning study. The M.S. program is a high level graduate program designed to refine critical thinking skills necessary for making you an industry leader.

Degree Requirements

The program for a Master of Science in fire protection engineering is flexible and can be tailored to individual student career goals. The fire protection engineering master's degree requires 30 credits. Both a thesis and non-thesis option are offered. A 9-credit thesis can replace 9 credits of course work. All M.S. students are required to take 9 credits of core classes; FP 521, FP 570, FP 553, and at least one Fire Protection Integration course; FP 571 and/or FP 573. The remaining 18 credits are chosen by the student and up to 9 credits can be taken outside of the Fire Protection discipline (with academic advisors approval).

Type: Master of Science

Ph.D. in Fire Protection Engineering

The Ph.D. degree in the department of Fire Protection Engineering will focus on a program that produces scholars capable of creating new knowledge for the field. Our Ph.D. graduates will function at a high level no matter where they work or go in the profession.

Degree Requirements

The degree of Doctor of Philosophy is conferred on candidates in recognition of high scientific attainments and the ability to conduct original research. Ph.D. students must complete a minimum of 90 credits of graduate work after the bachelor's degree (or 60 credits after the master's). This includes at least 15 credits of fire protection engineering course credits and 30 hours of dissertation research.

Doctoral students must successfully complete the fire protection engineering qualifying examination, a research proposal and public seminar, and the dissertation defense.

Type: Ph.D.

Interactive Media & Game Development

Faculty

E. O. Agu, Professor; Ph.D., University of Massachusetts, 2001. Computer graphics, wireless networking, and mobile computing.
S. Barton, Associate Professor; Ph.D. University of Virginia, 2012. Human- robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.
S. Bhada, Assistant Professor, Systems Engineering; Ph.D., University of Alabama. Modeling based systems engineering (MBSE), engineering education and team mental models.
F. J. Chery, Assistant Teaching Professor; M.F.A., FullSail University, 2010. 3D Rigging/technical art, digital sculpting, futurism, expressive game mechanics, motion capture, photogrammetry.
K. Ching, Assistant Professor; Ph.D., Massachusetts Institute of Technology; entrepreneurial strategy, economics of science and innovation, science and innovation policy, digitization, data science.
M. L. Claypool, Professor; Ph.D., University of Minnesota, 1997. Distributed systems, networking, multimedia and online games.
J. deWinter, Professor; Ph.D., University of Arizona, 2008. Japanese game studies, experience design, virtual and augmented reality, games for social justice, production management and entrepreneurship in games.
E. Gutierrez, Assistant Professor; M.F.A., Academy of Art University, 2007. 2D/3D animation, concept art, digital painting, character design, short film production.
L. Harrison, Assistant Professor, Ph.D., University of North Carolina at Charlotte, 2013. Information visualization, visual analytics, perception and cognition of data, modeling and quantitative analysis of human behavior, statistical literacy.
N. T. Heffernan, Associate Professor; Ph.D., Carnegie Mellon University, 2001. Educational data mining, learning sciences and technology.
V. J. Manzo, Associate Professor; Ph.D. Temple University, 2012. Interactive music systems, algorithmic and traditional composition, electric guitar performance and innovation, music theory, music education.
B. J. Moriarty, Professor of Practice; M.Ed., Framingham State University, 2014. Digital games and culture, virtual communities, interactive fiction.
D. M. O'Donnell, Teaching Professor; M.F.A., Brandeis University, 1990. Game and level design, narrative, impact of new media on society, board game design, escape room design.

E. Ottmar, Assistant Professor, Ph.D., University of Virginia, 2011. Theories in developmental, educational, and cognitive psychology, and mathematics and teacher education.
C. D. Roberts, Assistant Professor; Ph.D., UC Santa Barbara, 2014. Computer music, creative coding, live coding, large-scale virtual reality, audiovisual authoring.
J. Rosenstock, Associate Professor; M.F.A., School of the Art Institute of Chicago, 2004. Multimedia performance, interactive installation art, electronic instrument design, light art, BioArt.
G. M. Smith, Associate Professor; Ph.D., UC Santa Cruz, 2012. Computational creativity, games and social justice, tangible computing, computer science education, computational craft, procedural generation.
R. P. H. Sutter, Senior Instructor/Lecturer; B.S., New England Institute of Art, 2010. 3D animation, digital sculpting/character creation, games, augmented reality, traditional animation and art.
K. Zizza, Instructor; Digital audio, game design.
A full listing can be found here:
https://www.wpi.edu/academics/departments/interactive-media-game-development/faculty-staff

Annual Progress Review Milestone

In addition to the milestones specific to each degree, all IMGD graduate students must participate in an annual progress review conducted by the program. Students submit a report describing the work they have completed that year and reflection on their progress. A faculty committee reviews each report, discusses student progress, and makes a decision about student continuation in the program. There are three potential recommendation outcomes from this review milestone: a) satisfactory progress, b) program warning, and c) program dismissal. If a student receives a warning, then they will receive constructive feedback on how to improve their performance. If the committee recommends the student for dismissal, they enter WPI's academic dismissal process as described in the "Academic Standards" section of this catalog.

Facilities/Research Labs /Research Centers

- IMGD Lab. 27-seat teaching/research lab.
- Zoo Lab. 25-seat teaching/research lab.
- Digital Art Studio. Work space for both digital and traditional art.
- Performance Evaluation of Distributed Systems (PEDS) Lab. Design and analysis of distributed systems, with a special focus on the performance on - networking.
- Mixed Reality Development Group. Design, implementation, and analysis of virtual and augmented reality systems.
- Music, Perception, and Robotics Lab. Musical creativity, perception and cognition, expressive robotic and mechatronic systems.

M.F.A. in Interactive Media and Game Design

Program Goals and Objectives

The Master of Fine Arts (MFA) degree is a terminal degree that focuses on the development and establishment of a creative practice and voice. After completing the MFA in Interactive Media and Game Design, students will be able to:

1. Contextualize their work in the history of their chosen medium as well as modern practice.
2. Respond to and deliver critique effectively.
3. Lead projects and collaborate effectively.
4. Create works that express their unique voice within their chosen medium.
5. Maintain a professional portfolio that effectively showcases their work.
6. Articulate their path for professional and artistic growth after graduation.

Curriculum

The MFA requires 51 credit hours, spread across Design Studio (12 credit hours), Core Coursework (21 credit hours), a professionalization requirement (6 credit hours), an elective (3 credit hours), and a thesis project (9 credit hours).

Admissions Requirements

In addition to the general requirements for admission into any graduate program at WPI https://www.wpi.edu/admissions/graduate/how-to-apply, applicants must submit the following credentials for an application to be complete:

1. Statement of purpose that details:
    1. the student's goals, and
    2. the student's previous industry or academic experiences.
2. An Artist's Statement that describes the student's artistic identity and vision
3. Portfolio

The range of potential IMGD MFA projects is broad--from digital games to interactive theater--and, as such, the range of skills required to achieve those projects is highly variable. Prospective students will be evaluated based on the admission committee's judgment of their likelihood to succeed in the program given their stated goals and prior experience.

Exit Requirements

1. Capstone project
2. Public presentation of capstone project
3. Portfolio (as a requirement of IMGD 6001, Job Colloquium)

Type: M.F.A.

Design Studio

IMGD Studio is taken every semester of the three year program.

Item #	Title	Credits
IMGD 5000	IMGD Studio	3

Core Courses

IMGD 5010 is a rotating special topics course. Students must take two different versions of this course during their degree.

Item #	Title	Credits
IMGD 5010	IMGD Fundamentals	3
IMGD 5100	Tangible and Embodied Interaction	3
IMGD 5200	History and Future of Immersive and Interactive Media	3
IMGD 5300	Design of Interactive Experiences	3
IMGD 5400	Production Management for Interactive Media	3
IMGD 5500	Serious and Applied Games	3

Professionalization

One IMGD Colloquium course is taken every year of the three year program. IMGD 6001 should be taken in the student's final year.

Three credits of graduate internship OR Completion of a Teaching Certificate

Item #	Title	Credits
IMGD 6000	IMGD Colloquium	1
IMGD 6001	IMGD Career Colloquium	1

Elective Courses

Students may choose any graduate level IMGD course, any 4000-level IMGD course (for two credits), or an elective course from the MS electives list.

Project

All students are required to complete an interactive or game project and show the game in a public forum open for public engagement and critique. The student's advisor is the instructor of record for these credits. The project must be approved by a committee of three faculty, comprised of the student's advisor and two additional members drawn from the IMGD faculty. Projects must be conducted by individuals; team-based projects are not permitted for the MFA.

M.S. in Interactive Media & Game Development

Program of Study

The Master of Science in Interactive Media & Game Development (IMGD) is designed for those interested in the design of immersive, interactive environments. The intended audience includes college graduates looking for continued education in interactive media, game-industry professionals looking to assume leadership roles, professionals from other fields retooling for the game industry, and those seeking scholarship in interactive media. Graduate students in IMGD: 1) take core courses that provide a base of knowledge relevant to the design of interactive media; 2) select courses from Technical, Serious Games, or Management Focus areas that enable tailoring the degree to suit interests and career goals; and 3) design, develop, and evaluate a substantial group project and/or undertake a thesis with novel scholarship as a capstone experience. Graduates with an IMGD graduate degree will be qualified to pursue a diverse range of careers in the interactive media, computer games, or related industries, becoming producers, designers, academics, or project leaders in specific subfields such as technology, art, or design.

Admission Requirements

- Statement of purpose that details:
  - the student's goals, and
  - the student's previous industry or academic experiences.
- Proof of a four-year degree. Applicants who are not participating in the B.S./M.S. program must submit a

final transcript showing that they have completed a bachelor's degree or its equivalent before enrolling in the M.S. program.
- Three letters of recommendation from individuals who can comment on the student's qualification for pursuing graduate study in IMGD.
- Applicants may submit other material supporting their application, such as a portfolio of their work.

More information on admissions can be found here: https://www.wpi.edu/academics/departments/interactive-media-game-development/resources/admissions-portfolio-guidelines

Degree Requirements

IMGD M.S. students undertake a Game Design Studio course (3 credit hours), a core course relevant to their focus area (3 credit hours) and two other core courses (6 credit hours) covering various aspects of design, supplemented by two courses (6 credit hours) supporting a focus area (Serious Games, Technical, or Production Management), and one elective course (3 credit hours). Each student is required to complete either a Master's thesis (a systematic approach to addressing an identified research question, typically done individually) or a Master's project (a substantial development effort that follows a production plan to implement a design vision, typically done in teams) to complete the degree requirements (9 credit hours).

The IMGD program also offers a B.S./M.S. program for current IMGD undergraduate students. Students enrolled in this program may count up to 12 credit hours of specific undergraduate courses towards both their B.S. and M.S. degrees.

Details on the degree requirements for both M.S. and B.S./M.S. students can be found here: http://imgd.wpi.edu/gradrequirements.html

Type: Master of Science

Game Design Studio

Item #	Title	Credits
IMGD 5000	IMGD Studio	3

Focus Area Core Course

Item #	Title	Credits
IMGD 5100	Tangible and Embodied Interaction	3
IMGD 5500	Serious and Applied Games	3
IMGD 5400	Production Management for Interactive Media	3

Core Course Electives

Item #	Title	Credits
IMGD 5100	Tangible and Embodied Interaction	3
IMGD 5200	History and Future of Immersive and Interactive Media	3
IMGD 5300	Design of Interactive Experiences	3
IMGD 5400	Production Management for Interactive Media	3
IMGD 5500	Serious and Applied Games	3
IMGD 5600	Multidisciplinary Research Methods in Computational Media	3

Focus Courses

- Technical Focus, or
- Serious Games Focus, or
- Management Focus

see details at https://www.wpi.edu/academics/study/interactive-media-game-development-ms

Elective Course

Selected from the courses in the Core and Focus areas, or

Item #	Title	Credits
IMGD 5099	Special Topics in IMGD	3

Thesis/Project

Ph.D. in Computational Media

Program Goals and Objectives

Doctor of Philosophy in Computational Media (CM) candidates conduct advanced study in areas of humanistic expression voiced through computational means. The program recognizes play and art as fundamentally important aspects of human experience that can be shaped in compelling ways via technological tools and methods. Conversely, computational research can find new trajectories via the exploration of art and play. Individual paths include the study and design of human-computer interfaces, games and game engines, narratives, artificial intelligence, creativity, communication, and visual and sonic media. As these journeys are inherently interdisciplinary, students will find opportunities to explore related fields including computer science, data science, electrical and computer engineering, systems dynamics, robotics engineering, business, and psychology.

After completing the PhD in Computational Media, students will be able to:

1. Conduct scholarly research on a professional level by articulating motivating research questions, comprehensively reviewing relevant literature, and implementing appropriate research methodologies.
2. Design and develop a portfolio of artifacts that expresses:
    1. Proficiency in both creative and technical practices.
    2. Expert knowledge of the prior art that defines a context at the intersection of human creativity and computation.
    3. Understanding of the opportunities and requirements for novel contribution to a canon that defines a scholarly field.
3. Explain how computational means reflect, inspire, and shape human creativity in the generation of new media.
4. Understand the benefits of interdisciplinary research and methodologies for conducting research in interdisciplinary teams.
5. Disseminate research in the venues that are most relevant and impactful and, in doing so, connect to communities that value their work.

Curriculum

The PhD requires 60 credit hours following the completion of a master's degree. These 60 credit hours are split between coursework (30 credits) and research (30 credits). All students are required to take 15 credits in the CM Core, fulfilling the following requirements:

- IMGD 5000, IMGD Studio.
- IMGD 5600, Multidisciplinary Research Methods in Computational Media.
- MGD 5200, History and Future of Immersive and Interactive Media.
- IMGD 5100, Tangible and Embodied Interaction.
- IMGD 5010, IMGD Fundamentals.*

* This is a rotating topics course. Students must take one versions of this course during their degree, which should be on a topic outside their prior academic preparation.

The remaining 15 credits should be fulfilled through open electives in areas related to CM. Students should work in collaboration with their advisor to choose these electives. In acknowledgment of the highly interdisciplinary nature of Computational Media, students are advised to choose courses from across the graduate catalog. Undergraduate courses count for 2 graduate credits and may be taken with approval of the student's advisor.

Students who enter the PhD in Computational Media via the IMGD MS program must fulfill any remaining CM Core courses that they have not already taken, and then take the remainder of their coursework requirement as open electives (including independent study).

Additional Degree Requirements

There are four major research milestones for PhD students, spread across the degree:

Paper requirement. The student should show evidence of having contributed to publishable work (e.g. primary authorship on a conference paper or journal article in a reputable venue). This milestone should be achieved by the end of year two, and must be approved by the student's thesis advisor and the IMGD graduate committee.

PhD qualifying exam. No later than the end of the student's fifth full semester in the PhD program, the student should complete a qualifying exam set by a committee of three faculty including the student's advisor. This committee should be the same as intended for their thesis proposal except for the external member. At least two members of this committee must hold a PhD. For their qualifying exam, the student defines their own research area in which they intend to become an expert, and sequentially complete the following milestones related to that area:

1. Conduct a thorough literature review, identifying themes and major research questions in that area. The literature list is initially proposed by the student, and modified then approved by the faculty committee.
2. A response to three questions, each posed by the faculty committee, that allows the student an opportunity to analyze, critique, and connect the ideas, themes and questions resulting from the literature review.
    1. At least one of these questions must be analytical in nature, in which the student responds by writing an essay that draws upon the literature in their area.
    2. At least one of the questions must be a prompt for making an artifact relevant to the candidate's area (e.g. a technical system implementation or a game prototype).
    3. Students will have two weeks to complete this requirement.
3. Give a 45 minute oral presentation that teaches about the core area of study the student has identified.
4. Design a syllabus for a graduate level special topics course that teaches about the identified area, to be approved by the faculty committee.

If the committee finds that a student did not successfully pass either (b) or (c), the student may make one additional attempt to pass per step. If the committee judges a repeated attempt to have failed, the student will be asked to leave the program.

Advancement to PhD candidacy. By the beginning of year four, the student should have assembled their PhD committee and complete their PhD proposal. This committee may change between the candidate's qualifying exam and PhD proposal; however, after advancing to candidacy changing a PhD committee requires approval by the IMGD graduate steering committee. The PhD committee must have the following general composition:

- the student's advisor,
- two faculty members internal to IMGD/CS/HUA,
- one external committee member, who may be either a tenure-track faculty member at WPI who is external to IMGD/CS/HUA, a faculty member at a different university, or a researcher in industry with equivalent qualifications to a tenure-track faculty member as judged by the IMGD graduate committee.

At least two members of the thesis committee must hold a PhD.

The thesis proposal is delivered as a written document, and also presented in a public forum followed by oral examination in a private session open only to the student and committee. The potential outcomes from the thesis proposal are: "pass", "pass with revisions", and "fail and re-propose". This is decided by committee vote following deliberations, for which the student is not present. If revisions are required, then they must be submitted in writing to the committee, but the student is not required to re-present their proposal.

Dissertation defense. The student must defend their written dissertation through an oral presentation that is open to the public, followed by a private defense with the committee members. Potential outcomes from the committee vote on a student's defense are: "pass with minor revisions", "pass with major revisions", and "fail and re-defend". Revisions are changes to the written dissertation. Minor revisions can be approved by the advisor alone, major revisions require the full committee to approve, and "fail and re-defend" requires the student to make substantial revisions to the research and to present again.

Admissions Requirements

In addition to the general requirements for admission into any graduate program at WPI (https://www.wpi.edu/admissions/graduate/how-to-apply), applicants must submit the following credentials for an application to be complete:

1. Statement of purpose that details:
    1. the student's goals, and
    2. the student's previous industry or academic experiences.
2. Portfolio or Work Sample

Students who apply to the CM PhD who do not yet have a master's degree should first enter the MS in IMGD. Students whose master's degree is in an area that is distant from IMGD may be encouraged by the graduate committee to take additional coursework as part of their PhD.

Type: Ph.D.

Interdisciplinary Programs

New fields of research and study that combine traditional fields in innovative ways are constantly evolving. In response to this, WPI encourages the formation of interdisciplinary graduate programs to meet new professional needs or the special interests of particular students.

Individually Designed Ph.D. Degrees

Students may design their own interdisciplinary Ph.D. program in consultation with faculty members relevant to the proposed project.

Individually designed Ph.D. degrees are initiated by a student with the support of groups of at least three full-time faculty members who share a common interest in a cross-disciplinary field. A sponsoring group submits to the Committee on Graduate Studies and Research (CGSR) a proposal for an individually designed, interdisciplinary degree, together with all the details of the degree requirements and the credentials of the members of the sponsoring group. At least one member of the group must be from a department or program currently authorized to award the doctorate. Typically the student is assigned a department that matches the department of the primary advisor.
If the CGSR approves the proposal, the sponsoring group serves in place of a department in the administration of the approved interdisciplinary program. Administrative duties include admitting and advising students, preparing and conducting examinations, and certifying the fulfillment of degree requirements.

In addition to the general requirements established by WPI for an Individually designed doctoral degree, applicants must pass a qualifying examination. This examination will test the basic knowledge and understanding of the student in the disciplines covered by the research as is normally expected of degree holders in the disciplines. It should be administered after completion of 18 credits but before completion of 36 credits of work in the interdisciplinary Ph.D. program. The examination will be administered by a committee of no less than three members, approved by CGSR, representing the disciplines covered by the research. Students are allowed at most two attempts at passing the examination, and may take a maximum of 18 credits prior to passage.

Individually Designed Master's Degrees

Individually designed master's degrees require at least 30 credits beyond the bachelor's degree. They may also include a thesis or project requirement. Proposals for such degrees are initiated by a student with the support of groups of at least two faculty members from different academic departments who share a common interest in a cross-disciplinary field. The sponsoring group submits a proposal for an individually designed, interdisciplinary degree to the Committee on Graduate Studies & Research (CGSR) that includes the details of a program of study and the credentials of the members of the group. At least one member of the group must be from a department or program currently authorized to award the master's degree. No more than half of the total academic credit may be taken in any one department. The CGSR may request additional input from the sponsors or appropriate departments. If the CGSR approves the proposal, the sponsoring group serves in place of a department in administration of the approved program. Typically the student is assigned a department that matches the department of the primary advisor.

Interdisciplinary graduate certificate and degree programs that are established and currently accepting students are: Aerospace Engineering, Bioinformatics and Computational Biology, Bioscience Management, Data Science, Information Security Management, Interactive Media & Game Development, Learning Sciences & Technologies, Materials Systems Engineering, Nuclear Science & Engineering, Power Systems Engineering, Power Systems Management, Robotics Engineering, Robotics Engineering Management, System Dynamics, System Dynamics and Innovation Management, Systems Engineering, Systems Modeling, and Systems Thinking.

Bioscience Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Program of Study

WPI offers graduate levels studies in the field of Bioscience Management leading to the Master of Science. This program is designed to offer both business and science education thus meeting an educational need in the life sciences and bioresearch fields. This degree is applicable for students seeking employment in pharmaceutical, biotechnology, and biomedical device companies. This program helps science professionals advance their science knowledgebase and also helps them build the necessary administrative infrastructure for their field.

Admissions Requirements

Admission for the Master's degree is consistent with the admission requirements listed in the Graduate Catalog for a Master of Science degree. Appropriate undergraduate bachelor's degree majors include but are not limited to life science, management, engineering, and computer science. Students with other backgrounds may be considered with the approval of the program administrator. Students need a working knowledge of basic biotechnology, biochemistry, cell biology, and chemistry.

Manufacturing Engineering Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Power Systems Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Programs of Study

- Interdisciplinary Master of Science in Power Systems Management
- Certificate in Power Systems Management

Power Systems Engineering education is in high demand in the United States and more so in developing nations. WPI has broadened its offerings of courses in this area, and now offers a new level of flexibility for students and their current or prospective employers. In addition, the School of Business provides an attractive palette of relevant courses to enhance the professional skills of practicing engineers. This framework has created programs to meet industry demands.

Admissions Requirements

Students will be eligible for admission into the program if they have earned an undergraduate degree from an accredited university consistent with the WPI Graduate Catalog. Normally, an undergraduate bachelor's degree in electrical engineering, computer engineering, or computer science is expected. Students with other backgrounds may be considered with the approval of the faculty. GRE examinations are required for all international applicants.

Systems Engineering Leadership

Program of Study

The program allows students to increase their knowledge and skills in systems engineering while simultaneously increasing their business acumen. This interdisciplinary program blends technical training with business disciplines to provide critical skills and knowledge for leaders in highly technical and complex fields. The prescribed coursework will also enhance the students' ability to predict and model the impact of change in complex systems. Graduates will possess the skills necessary to holistically view, design and maintain complex systems and projects, and make effective business decisions as leaders in their organizations.

Admissions Requirements

The M.S. in Systems Engineering Leadership aims to attract candidates from a range of educational backgrounds that includes science, engineering, various business disciplines, and more. This flexible program was designed to attract candidates who possess a technical background and are looking to build their leadership skills, as well as those who may not have an engineering background and are seeking technical knowledge to continue their career growth within their organizations. The following will be required to be considered for admission:

- Official transcripts for all post-secondary colleges or universities showing that a bachelor's degree has been earned from a regionally accredited institution.
- Three letters of professional recommendation from individuals who can comment on student qualifications for pursuing graduate study.
- Statement of purpose
- Résumé
- •GMAT or GRE scores—may be waived for candidates who hold a bachelor's degree from a regionally accredited institution with a minimum 3.0 GPA, with a course of study that included at least two quantitative courses with a grade of 3.0 or higher AND who meet one or more of the following three requirements:
    - Three or more years of professional work experience
    - A professional certification such as INCOSE SEP, PMI PMP, CPA, CFA, CFP, or Six Sigma.
    - An existing master's or earned doctorate with a GPA of 3.0 or higher

Certificate in Nuclear Science and Engineering

Faculty

The faculty hold a full time position in a WPI academic department or are adjunct faculty approved by an academic department and the NSE program review committee.

Program of Study and Certificate Requirements

The graduate certificate in nuclear science and engineering will require the successful completion of 12 graduate credits with an overall GPA of 3.00. The courses will be selected from the list below.

Admissions Requirements

Admission to the Nuclear Science and Engineering graduate certificate program is consistent with the admissions requirements listed in this catalog for graduate certificates. Appropriate undergraduate degree majors include all engineering and science majors.

Type: Certificate

All students must successfully complete four of the five courses listed below:

Item #	Title	Credits
NSE 510	Introduction to Nuclear Science and Engineering	3
NSE 520	Applied Nuclear Physics	3
NSE 530	Health Physics	3
NSE 540	Nuclear Materials	3
NSE 550	Reactor Design, Operations, and Safety	3

Certificate in Power Systems Management

This certificate program is proposed to meet the needs of a variety of corporations and individuals who are taking a first step toward an M.S. in Power Systems Management. The framework presents minimum requirements for the distribution of power systems and management courses, but provides flexibility for the student.

This certificate must consist of at least 17 credits of graduate coursework.

For more information please consult the WPI web at https://www.wpi.edu/academics/departments/power-systems

Type: Certificate

Graduate Certificate in Life Science Management

This certificate program is designed to meet the needs of a variety of corporations and individuals who are interested in honing advanced technical and business skill sets necessary to fill leadership roles within the life science industry. Inherent in the program of study is sufficient course selection flexibility for students to, if desired and admitted, be able to continue their graduate studies and earn an MS degree in Biotechnology, Biochemistry, or Bioscience Management, depending on student interest and background. The program of study requires 12 credits of coursework chosen from amongst our life science and management course offerings:

Type: Certificate

At least six credits must be chosen from courses thematically-related to the life sciences and may include those with a prefix of BB, BCB, CH, or other approved department by the CBC faculty administrator (for ex. BME, CHE)

At least three credits of management coursework, typically chosen from amongst the following list of courses:

Item #	Title	Credits
BUS 546	Managing Technological Innovation	3
ETR 593	Technology Commercialization	3
MIS 576	Project Management	3
OBC 505	Teaming and Organizing for Innovation	3
OBC 506	Leadership	3
OBC 533	Negotiations	3
OBC 537	Leading Change	3
OIE 542	Risk Management and Decision Analysis	3
OIE 548	Performance Analytics	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

Interdisciplinary Master of Science in Bioscience Management

Admission

All applicants for this program must hold a bachelor's degree from an accredited college or university recognized by WPI. Acceptable bachelor's degrees include life science, management, engineering, and computer science. Students with other backgrounds may be considered with the approval of the program administrator. GRE and GMAT examinations are not required for admission to the program.

Requirements

Awarding of the degree requires successful completion of at least 30 credit hours of graduate coursework, not to exceed 14 credit hours in Biomedical engineering, within the Bioengineering or Custom Science tracks, and no more than 12 credit hours from any other discipline, including required or elective courses or directed research credits.

Curriculum

The Master of Science in Bioscience Management consists of three track options: Life Science, Bioengineering, and Custom Science. Although the courses are not specified in any of the tracks, the number of credit hours completed

must conform to the breakdown found Table I.
Each student must have a Plan of Study approved by the program administrator within their first 9 credits.

Transfer Credits

Consistent with WPI policy in most graduate areas, up to one-third of the degree program (10 credit hours) may be transferred from an accredited college or university with approval of the program administrator.

Type: Master of Science

Table I: Three track options for the Master of Science in Bioscience Management

Life Science Track:

6-12 Credit Hours in Chemistry/Biochemistry
6-12 Credit Hours in Management
6-12 Credit Hours in Biology/Biotechnology
3-9 Credit Hours of electives or directed research

Bioengineering Track:

9-14 Credit Hours in Biomedical Engineering
6-12 Credit Hours in Management
3-12 Credit Hours in Chemistry or Biology
3-9 Credit Hours of electives or directed research

Custom Science Track:

16-24 Credit Hours selected from Biomedical Engineering, Biology/Biotechnology, Chemistry/Biochemistry, Computer Science, Mathematical Science
6-12 Credit Hours in Management

Interdisciplinary Master of Science in Manufacturing Engineering Management

This program is designed to meet the demand from professionals who typically have an undergraduate degree in engineering, work experience in manufacturing, and a desire to pursue a master's degree curriculum with equal emphasis in both manufacturing engineering and manufacturing/operations management. They project their career as continuing to need a balanced growth in manufacturing engineering and manufacturing management.

Admissions Requirements

Students will be eligible for admission into the program if they have earned an undergraduate degree from an accredited university consistent with the WPI Graduate Catalog. Students should have a bachelor's degree in science or engineering. Students with other backgrounds will be considered based on their interest, formal education and experience in manufacturing. Admission decisions will be made by the sponsoring faculty based on all factors presented in the application, including prior academic performance, quality of professional experience, letters of recommendation, etc.

Degree Requirements

Students must complete 30 credit hours of course work in Manufacturing, Engineering, and Management related courses as defined by the coordinating faculty.

Type: Master of Science

Business

Choose 12 credits

Item #	Title	Credits
BUS 546	Managing Technological Innovation	3
MIS 500	Innovating with Information Systems	3
MIS 576	Project Management	3
OBC 505	Teaming and Organizing for Innovation	3
OBC 537	Leading Change	3
OIE 542	Risk Management and Decision Analysis	3
OIE 544	Supply Chain Analysis and Design	3
OIE 548	Performance Analytics	3

Engineering

choose 15 credits

Item #	Title	Credits
MFE 510	Control and Monitoring of Manufacturing Processes	3
MFE 511	Application of Industrial Robotics	2
MFE 520/MTE 520/ME 543	Axiomatic Design of Manufacturing Processes	3
MFE 531/ME 5431	Computer Integrated Manufacturing	2
MFE 541/ME 5441	Design for Manufacturability	2
MFE 598	Directed Research	3

Interdisciplinary Master of Science in Power Systems Management

At least 30 credit ours composed of:

- At least 12 credits but no more than 15 credits of graduate level coursework in Power Systems Engineering (course prefix ECE with course numbers from 5500 through 5599)
- At least 12 but no more than 14 credits of graduate level coursework in Business (example courses prefixed by BUS, MIS, OBC, OIE, etc.).

Electives:

Under the direction of the advisors, each student will select 6 credits of coursework at the 4000 level (maximum of two) or at the graduate level (designated as 500-, 5000-, or 600-level) in computer science (CS), physics (PH), engineering (BME, CHE, CE, ECE (1 only), FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or Systems Dynamics (SD) to complete the Interdisciplinary Master of Science degree.

There is no thesis option for this degree.

Type: Master of Science

Interdisciplinary Master of Science in Systems Engineering Leadership

This interdisciplinary program requires 30 graduate credit hours of graduate-level work, distributed as follows:

Type: Master of Science

12 Credits in Business Courses

(Choose one from each category)

3 Credits in Leadership/Organizational Behavior and Change

from the following list*:

or other course(s) in the area with prior Program Review Board approval

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
OBC 506	Leadership	3
OBC 533	Negotiations	3
OBC 537	Leading Change	3

3 Credits in Finance

from the following list*:

or other course(s) in the area with prior Program Review Board approval

Item #	Title	Credits
FIN 503	Financial Decision-Making for Value Creation	3

3 Credits in Marketing, Strategy, or Entrepreneurship

from the following list*:

or other course(s) in the area with prior Program Review Board approval

Item #	Title	Credits
BUS 546	Managing Technological Innovation	3
ETR 500	Entrepreneurship and Innovation	3
ETR 593	Technology Commercialization	3
MKT 500	Marketing Strategy	3
MKT 568	Data Mining Business Applications	3

3 Credits in Information Technology

from the following list*:

or other course(s) in the area with prior Program Review Board approval

Item #	Title	Credits
MIS 500	Innovating with Information Systems	3
MIS 571	Database Applications Design and Development	3
MIS 573	System Design and Development	3
MIS 584	Business Intelligence	3

12 Credits in Systems Engineering Courses

Item #	Title	Credits
SYS 501	Concepts of Systems Engineering	3
SYS 502	Business Practices	3
SYS 540	Introduction to Systems Thinking	3
SD 550	System Dynamics Foundation: Managing Complexity	3

3 Credits in Technical Electives

Any other graduate-level SYS course with Program Review Board approval (3 Credits)

3 Credit Required Capstone Project

Item #	Title	Credits
IDG 598	Systems Engineering Leadership Project	0

Learning Sciences and Technologies

Faculty

Learning Sciences & Technologies Core Faculty

N. T. Heffernan, The William Smith Dean's Professor of Computer Science and Director of Learning Sciences and Technologies; Ph.D., Carnegie Mellon University; Intelligent tutoring agents, artificial intelligence, cognitive modeling, machine learning
J. E. Beck, Associate Professor; Ph.D., University of Massachusetts, Amherst; educational data mining, student modeling, Bayesian Networks, student individual differences
S. Djamasbi, Professor; Ph.D., University of Hawaii at Manoa; Usability, decision science.
L. Harrison, Associate Professor; Ph.D., University of North Carolina at Charlotte; Information visualization, visual analytics, human-computer interaction.
E. Ottmar, Assistant Professor; Ph.D., University of Virginia; mathematics teaching and learning; mathematics development and cognition; interventions in schools; instructional quality; social and emotional learning; motivation and engagement; perceptual learning; teacher/child interactions; observational measurement development
A. C. Sales, Assistant Professor; Ph.D., University of Michigan, Ann Arbor; analysis of educational data, log data from intelligent tutors, causal inference, causal mechanisms, randomized experiments, observational studies.
S. T. Shaw, Assistant Professor; Ph.D., University of California, Los Angeles: teaching and learning in mathematics, creativity, statistics education, math anxiety.
G. B. Somasse, Associate Teaching Professor; Ph.D., Clark University; Development economics, applied econometrics, policy evaluation, public policy.
J. R. Whitehill, Assistant Professor; Ph.D., University of California, San Diego; Machine learning, crowdsourcing, automated teaching, human behavior recognition.
J. Zou, Associate Professor; Ph.D., University of Connecticut; Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Learning Sciences & Technologies Associated Faculty

I. Arroyo, Associate Professor; Ed.D., M.S., University of Massachusetts, Amherst; learning with novel technologies; multimedia learning; intelligent tutoring systems; wearable learning and e-Textiles; learner characteristics and their relationship to learning; connection between affect and learning; educational data mining and student modeling.
R. Baker, Assistant Professor; Ph.D., Carnegie Mellon University; educational data mining, learner-computer interaction, gaming the system, student modeling, intelligent tutoring systems, educational games.
D. C. Brown, Professor; Ph.D., Ohio State University; Knowledge-based design systems, artificial intelligence
J. K. Doyle, Associate Professor; Ph.D., University of Colorado/Boulder; judgement and decision making, mental models of dynamic systems, evaluation of interventions
G. T. Heineman, Associate Professor; Ph.D., Columbia University; Component-based software engineering, formal approaches to compositional design
A. C. Heinricher, Professor; Ph.D., Carnegie Mellon University; applied probability, stochastic processes and optimal control theory

C. Ruiz, Professor; Ph.D., University of Maryland; Data mining, knowledge discovery in databases, machine learning
J. L. Skorinko, Professor; Ph.D., University of Virginia; social environmental cues, stigmas and stereotyping, perceptions of others
G. M. Smith, Associate Professor and Director of Interactive Media and Game Development; Ph.D., UC Santa Cruz, 2012. Computational creativity, games and social justice, tangible computing, computer science education, computational craft, procedural generation.
S. Stanlick, Assistant Professor and Director of the Great Problems Seminar; Ph.D., Lehigh University; learning sciences and technology, public interest technology, global citizenship, digital sociology, ethics, transformative learning

Program of Study

The Learning Sciences and Technologies (LS&T) program offers graduate studies toward the M.S. and Ph.D. degrees. Our state-of-the-art facilities, faculty and strong relationships with K-12 schools provide students with the resources to perform innovative scientific research at the highest level. The diverse learning environment that characterizes our program promotes easy exchange of ideas, access to all the necessary resources, and encourages creative solutions to pressing scientific questions. The LS&T program is based on three affiliated areas – Computer Science, Cognitive and Educational Psychology, and Statistics – and provides opportunities for advanced course work and research for highly qualified students.

Admissions Requirements

Applicants must apply directly to the LS&T program. In order to be capable of performing graduate level work, applicants should have background in at least one of the core disciplines of LS&T, namely, Cognitive/Educational Psychology, Computer Science, or Statistics. We will also consider applicants whose academic background is in Science or Math.

A student may apply to the Ph.D. program in LS&T after completing a bachelor's degree (in which case a master's degree must first be completed) or a master's degree in one of the affiliated areas (Computer Science, Cognitive or Educational Psychology or Statistics) or a closely related area. Applicants with other degrees are welcome to apply if they can demonstrate their readiness through other means, such as GRE Subject exams in an affiliated area, or through academic or professional experience. GRE scores are strongly recommended, but not required, for all applicants. Inquiries about the GRE should be made to Dr. Neil Heffernan, the Program Director.

No Combined B.S./M.S. Degree

The LS&T program does not offer a combined B.S./M.S. degree.

Research Labs/Research Groups

Causal Modeling Research Group

Prof. Sales

We build, analyze, and evaluate statistical causal models, primarily for large, complex, or messy datasets such as log data from EdTech or state administrative data. Our research includes developing novel principal stratification models for implementation and/or computer log data from randomized trials; methods for incorporating auxiliary data and machine learning into classical analyses of A/B tests, RCTs, or observational matching designs; and regression discontinuity analysis with flexible covariance models.

Creativity, Education, Affect, and Reasoning (CEDAR) Lab

Prof. Shaw

The CEDAR Lab conducts research on creative and flexible thinking in mathematics, reasoning of complex concepts, and how student experiences shape thinking and learning in STEM education. Our lab uses experimental methods, observational data, learning analytics, and qualitative methodologies in an effort to better understand teaching and learning in STEM subjects. See more at cedarlab.org

Educational Data Mining Research Group

Profs. Beck, Heffernan, Whitehill & Arroyo

Large datasets of students' fine-grained interactions (e.g., student S answers math problem X with answer Y at time T) with intelligent tutoring systems, educational interventions, and massive open online courses (MOOCs) enable the exploration and optimization of how learners learn and how teachers teach. By harnessing methods from machine learning -- such as probabilistic graphical models, Markov chains, and deep neural networks -- we can develop more accurate predictors of which and when students will succeed, fail, persist, need help, etc. These predictors can, in turn, serve as the basis for both human-assisted and automated interventions to improve students' learning outcomes and the personalization of learning.

Embodied Cognition In Mathematics Research Group

Profs. Arroyo & Ottmar

This research group carries out research about new ways of learning, using motor actions as well as cognitive thought. We investigate how children may better learn mathematics while exploring the physical space, getting a different understanding of math learning by gesturing, and using technology to guide them through 3D spaces.

Machine Perception of Human Learning Group

Profs. Whitehill, Heffernan & Beck

This group uses machine learning and computer vision to study how learners learn and how they emote while they learn. Particular interests include the training of deep neural networks to recognize students' facial expressions during learning tasks, and the development of real-time cyberlearning systems that respond instantaneously to learners' current cognitive, affective, and linguistic needs.

Math, Abstraction, Play, Learning, And Embodiment (MAPLE) Lab

Prof. Ottmar

Teaching and learning mathematics is a highly complex social, exploratory, and creative process. We design novel dynamic technologies that make "math come alive" (Graspable Math, From Here to There!) and use eye tracking, mouse gestures, and log files to explore the coordination of attention, cognition, gestures, and strategies when solving mathematical equations. We also use a variety of applied multilevel quantitative methods, observational measures, and assessments to examine the efficacy of instructional, social, and emotional classroom Interventions that can improve K-12 math teaching, learning, and engagement. https://sites.google.com/site/erinottmar/

Quantitative Methods in the Learning Sciences

Profs. Somasse, Ottmar, Zou, Heffernan & Sales

This research group is focus on rigorous quantitative methods such as hierarchical linear models (which is a typical method to use when students are nested inside teachers and teachers are nested inside schools). Other topics include issues that are used a lot in Learning Science like structural question modeling, longitudinal data analysis, propensity score matching, regression discontinuity designs, quasi-experimental designs and advanced topics like principal stratification. The faculty in this group like to apply (and adapt) statistical methodologies to solves the problems they are working on.

Running Classroom Experiments on the Web

Profs. Heffernan, Beck, Ottmar, Arroyo, Whitehill & Sales

We use a number of web-based platforms and technologies (i.e. ASSISTments, MathSpring, GraspableMath) to conduct randomized-controlled trials in K-12 mathematics classrooms. These studies help us understand "what works" with regards to different pedagogical techniques, content, feedback, and tasks, and helps us develop a better understanding of the mechanisms guiding learning. Together the group has over 100 randomized controlled trials running each year. There are a set of methodologic issues that their research group tackle related to student-level randomized controlled assignment.
http://www.neilheffernan.net/

M.S. in Learning Sciences and Technologies

The student may choose between two options to obtain the M.S. degree: thesis or coursework. Students should carefully weigh the pros and cons of these alternatives in consultation with their LS&T faculty advisor prior to selecting an option. Completion of the M.S. degree requires 33 graduate credit hours. M.S. LS&T students who wish to become doctoral candidates in LS&T must first complete their M.S. degree in LS&T following the thesis option.

To satisfy the interdisciplinary nature of the LS&T program, each M.S. student must complete the following 15 graduate credit hours that form the core requirements.

- Computer Science Requirement [6 graduate credit hours]
    - Two LS&T Computer Science courses
- Cognitive Psychology Requirement [6 graduate credit hours]
    - Two LS&T Cognitive Psychology courses
- •Statistics Requirement [3 graduate credit hours]
    - One LS&T Statistics course; or
    - CS 567. Empirical Methods for Human-Centered Computing

No single graduate course can be double counted to satisfy two of the above requirements.

M.S. in LS&T – Coursework Option

In addition to the 15 graduate credit hours as required by the M.S. core requirements, a student pursuing the coursework option must register for an additional six graduate courses (totaling 18 graduate credit hours). To ensure a sufficient focus on LS&T, two of these courses (for a total of 6 graduate credit hours) must be from the LS&T course list. The remaining four courses (for a total of 12 graduate credit hours) are electives that relate to the student's individual program of study and must be selected in consultation with the student's LS&T advisor.

Note that M.S. graduate credits cannot be from independent study/research courses except by approval of the LS&T Program Director.

M.S. in LS&T – Thesis Option

In addition to the 15 graduate credit hours as required by the M.S. core requirements, a student pursuing the thesis option must satisfactorily complete a written thesis. Any Core or Associated LS&T faculty may serve as the thesis advisor. A thesis consisting of a research or development project worth a minimum of 9 graduate credit hours must be completed and presented to the LS&T faculty. A thesis proposal must be approved by the Core LS&T faculty and the student's advisor before the student can register for more than four thesis credits.

To complete the remaining 9 graduate credit hours, the student must register for an additional three graduate courses. To ensure a sufficient focus on LS&T, two of these courses (for a total of 6 graduate credit hours) must be from the LS&T course list. The remaining course (of 3 graduate credit hours) is an elective that relates to the student's individual program of study and must be selected in consultation with the student's LS&T advisor. As for the coursework option, M.S. graduate credits cannot be from independent study/research courses except by approval of the LS&T Program Director.

Type: Master of Science

Ph.D. in Learning Sciences and Technologies

Students are advised to contact the program director for detailed program guidelines, in addition to the university's requirements for the Ph.D. degree. Students who wish to pursue a Ph.D. in LS&T who completed their M.S. at WPI in LS&T, must have chosen the thesis option.

Fundamentally, it is expected that all LS&T Ph.D. students master the basics of Learning Sciences, apply those concepts to create an innovative technology, and properly analyze their work with the appropriate statistical techniques. Ph.D. students will receive training through a combination of enrolling in courses, satisfying competency requirements and completing a dissertation; all Ph.D. students will be reviewed by the Core LS&T faculty at least once a year to see that they are making satisfactory progress towards these three components of the Ph.D. program.

Course Requirements

The Ph.D. degree in LS&T requires an additional 60 graduate credit hours of work beyond the M.S. degree. Students must take a minimum of 30 graduate credit hours of course work, including independent study, and 30 graduate credit hours of research.

To satisfy the interdisciplinary nature of the LS&T program, each Ph.D. student must complete the following 24 graduate credit hours. To count towards the course requirements, students must get a minimum grade of B for each of the courses. Students receiving a C or below must retake a course in the appropriate area and receive a B or higher.

- Computer Science Requirement [9 graduate credit hours]
  - Three LS&T Computer Science courses
- Cognitive Psychology Requirement [9 graduate credit hours]
  - Three LS&T Cognitive Psychology courses
- Statistics Requirement [6 graduate credit hours]
  - LS&T Statistics courses, or
  - CS 567. Empirical Methods for Human-Centered Computing

All students are required to submit a program of study that describes their planned course work; their LS&T advisor must approve the program. These classes can include graduate classes at WPI, classes at Clark University, particularly from their Psychology Department, and from independent studies. However, to ensure depth in LS&T, no more than 9 credit hours can be from disciplines other than Cognitive Psychology, Computer Science, and Statistics except by the approval of the Program Director.

Students can count previously taken LS&T courses towards these requirements. However, students must still complete 30 graduate credit hours of coursework for the Ph.D. degree. For example, if a student had taken two LS&T Computer Science courses as part of an LS&T M.S. degree, only one more LS&T Computer Science course would be required, but the student would still have to complete 30 graduate credit hours of coursework for the Ph.D. Similarly, students who are transferring in with an M.S. degree will be evaluated for which requirements they have fulfilled, but will still be required to take 30 graduate credit hours of coursework.

To complete the remaining 6 graduate credit hours, the Ph.D. student can register for other graduate courses or independent studies with approval of the student's LS&T advisor.

Competency Requirements

In addition to successful completion of their coursework, Ph.D. students must demonstrate competency in two core areas: Data Analysis and Communication (specifically, Speaking and Writing). Regarding Data Analysis, it is expected that students will learn analysis methods relevant to the Learning Sciences. We have selected these two areas as they are fundamental to success as an empirical scientist and will form the basis of LS&T graduates' future careers. Competency in both Data Analysis and Communication will be assessed as follows: Students will be expected to conduct a pilot research study towards their graduate research. Students will submit a short paper (10-20 pages) to the Core LS&T faculty who will write a set of questions to be asked during a public presentation by the graduate student of the pilot research project. Possible venues for this include the AIRG (Artificial Intelligence Research Group) or the Learning Sciences Seminar. Students will be graded by at least two Core LS&T faculty on their responses to the LS&T questions, their data analysis, and communication skills at handling spontaneous questions during the talk. This requirement will be handled by the Core LS&T faculty.

Students must complete this competency requirement prior to defending their Ph.D. proposal. Furthermore, competency requirements must be completed within four semesters after students begin as Ph.D. students, except by permission of the Program Director.

Dissertation Requirements

Within six semesters of being admitted to the LS&T Ph.D. program, each student must form a dissertation committee, and write and defend a dissertation proposal. Any deviation from the timetable for the dissertation must be approved by the Program Director. Any Core or Associated LS&T faculty may serve as a research advisor.

A student's dissertation committee is composed of at least four members, as approved by the LS&T Core faculty. The committee must contain at least one Core LS&T faculty member and one faculty member external to WPI. To reinforce the interdisciplinary nature of the degree, at least two of the three cooperating departments (Computer Science, Social Science and Policy Studies and Mathematical Sciences) must have a faculty member on the dissertation committee. The dissertation committee will be responsible for approving the dissertation proposal and final report.

Students must enroll in at least 30 credits for their dissertation. Before presenting and defending their dissertation proposal, students may only enroll in 15 graduate research credit hours. Students are expected to defend their dissertation within six semesters of the acceptance of their dissertation proposal. In addition to the minimum of 30 graduate credit hours of research, the dissertation culminates in the student submitting the document itself and a public defense of the research.

Type: Ph.D.

Manufacturing Engineering

Faculty

B. Mishra, Kenneth G. Merriam Professor, Director, Materials & Manufacturing Engineering, Metal Processing Institute; Ph.D., University of Minnesota. Physico-chemical processing of materials; Corrosion science and engineering; Materials Processing, Surface Engineering, Resource Recovery & Recycling, Critical materials extraction; Iron and steelmaking; Alloy development; Thin film coatings.
C. A. Brown, Professor, Director, Surface Metrology Laboratory; Ph.D., University of Vermont. Surface metrology, multi-scale geometric analyses, axiomatic design, sports engineering, and manufacturing process.
M. S. Fofana, Associate Professor; Ph.D., University of Waterloo, Waterloo, Canada. Nonlinear delay dynamical systems, stochastic bifurcations, regenerative chatter, numerically controlled CAD/ CAM machining.
C. Furlong, Professor; Ph.D., Worcester Polytechnic Institute. MEMS and MOEMS, nanotechnology, mechatronics, laser applications, holography, computer modeling of dynamic systems.
S. A. Johnson, Professor; Ph.D., Cornell University. Lean process design, enterprise engineering, process analysis and modeling, reverse logistics.
D. A. Lados, Milton Prince Higgins II Professor; Director, Integrative Materials Design Center (iMdc); Ph.D., Worcester Polytechnic Institute, 2004; Fatigue, fatigue crack growth, and fracture of metallic materials – life predictions, computational modeling and ICME, materials/process design and optimization for aerospace, automotive,

marine, and military applications.
J. Liang, Professor; Ph.D., Brown University. Nanostructured materials, material processing, material characterization.
M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute. Solidification of Metals, the application of heat, mass and momentum transfer to modeling and solving engineering materials problems, and processing of ceramic materials.
R. D. Sisson Jr., George F. Fuller Professor; Director, Manufacturing and Materials Engineering; Ph.D., Purdue University. Materials process modeling, manufacturing engineering, corrosion, and environmental effects on metals and ceramics.
D. Strong, Professor of Management and Department Head; Ph.D., Carnegie-Mellon University; Director, Management Information Systems (MIS) Program; MIS and work flows, data integration and role changes; MIS quality issues, data and information quality.
W. Towner, Associate Teaching Professor; Ph.D., Worcester Polytechnic Institute; operations management, lean manufactur- ing, six-sigma.
B. Tulu, Associate Professor of Management; Ph.D., Claremont Graduate University. Medical informatics, information security, telemedicine, personal health records, systems analysis and design.
Y. Wang, Professor of Mechanical Engineering; Ph.D., University of Windsor (Canada). Lithium ion battery, fuel cell, corrosion and electrochemistry, flow battery.

Faculty Research Interests

Current research areas include additive manufacturing, tolerance analysis, CAD/CAM, production systems analysis, machining, fixturing, delayed dynamical systems, nonlinear chatter, surface metrology, fractal analysis, surface functionality, metals processing and manufacturing management, axiomatic design, and abrasive processes, electronic medical records, lean in health care and health dynamics.

Programs of Study

The Manufacturing Engineering (MFE) Program offers two graduate degrees: the master of science and the doctor of philosophy. Full- and part-time study is available.

The graduate program in manufacturing engineering provide opportunities for students to study current manufacturing techniques while allowing each student the flexibility to customize their educational program. Course material and research activities often draw from the traditional fields of computer science, controls engineering, electrical and computer engineering, environmental engineering, industrial engineering, materials science and engineering, mechanical engineering, and management. The program's intention is to build a solid and broad foundation in manufacturing theories and practices, and allow for further concentrated study in a selected specialty.

The Manufacturing Engineering Program also offers a B.S./M.S. program for currently enrolled WPI undergraduates. There is no undergraduate B.S. degree option in Manufacturing Engineering; the B.S. portion of this combined degree may be in any other discipline.

Admission Requirements

Candidates for admission must meet WPI's requirements and should have a bachelor's degree in science, engineering, or management, preferably in such fields as computer science/engineering, electrical/ control engineering, industrial engineering, environmental engineering, manufacturing engineering, materials science and engineering, mechanical engineering, or management. Students with other backgrounds will be considered based on their interest, formal education and experience in manufacturing.

For admission in to BS/MS program, Students should apply during their junior or senior year. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher. A grade of B or better is required for any course to be counted toward both degrees. Waiver of any of these requirements must be approved by the Manufacturing Engineering Graduate Committee, which will exercise its discretion in handling any extenuating circumstances or problems.

MFE Seminar

Seminar speakers include WPI faculty and students as well as manufacturing experts and scholars from around the world. Registration for, attendance at and participation in the seminar course, MFE 500, is required for full-time students. The seminar series provides a common forum for all students to discuss current issues in manufacturing engineering.

Research Facilities and Laboratories

The CAM Laboratory

The CAM Lab facilitates the use of digital technologies to model, analyze, and control the manufacturing processes and systems. Besides the computers available for students, several application software packages have been used for CAD, solid modeling, kinematic analysis, FEA, modeling and simulation of machining and other materials processing, as well as new additive manufacturing processes. The lab has been developing techniques and systems for process (machining and heat treatment) modeling and simulation, production planning, tolerance analysis, fixture design, and lean manufacturing.

Manufacturing Interpreting Robotics Analysis Delay Dynamical Systems Laboratory (MIRAD)

The MIRAD laboratory focuses on developing computation, technology and engineering to better improve emergency medical services, ambulance vehicles, dialysis treatment, medical and public health systems, aircraft breaking systems, systems engineering mechanics and automated manufacturing systems design. Our innovative computerized modelling techniques, simulations, experiments and computer-controlled data acquisition to understand vibrations and quantify uncertainty enable us to estimate optimal performance reliance of products, processes and systems in sustained ways. The partners of MIRAD Laboratory include but not limited to industry, academia, hospitals, EMS departments, research institutions and universities.

Manufacturing Laboratories

The manufacturing laboratories are spread out in six main areas in two buildings and house WPI's Haas Technical Education Center as well as WPI's Robotics Resource Laboratory, WPI's Collablab, and several student work spaces. In the Higgins Laboratories the facilities are located in rooms 004, 005, and 006. In the Washburn Shops the facilities are located in rooms 105, 107, and 108. The facilities are operated by an operations manager, and two lab machinists who are assisted by up to 20 undergraduate peer learning assistants (PLAs). Over 1000 WPI students use the facilities each year completing hundreds of individual and group projects. In a typical 7 week term we record over 4000 instances of use in the facilities which are available for student use 24 hours per day 365 days per year.

The Haas Technical Education Center was established with a $400,000 award from the Fleet Asset Management, trustee of the Elizabeth A. Lufkin Trust and Haas Automation, Oxnard, California, and represented in New England by Trident Machine tools, who entrusted WPI with over a quarter million dollars in new machine tools, software and training.

The center is used for both undergraduate teaching and graduate research. The eleven CNC machine tools are used in ME 1800, ME 3820, and ES 3323, as well as other courses. The machine tools facilitate the realization, i.e. fabrication, of parts that students have designed on computers. The machine tools are important for supporting WPI's project based-education. The machine tools are also be used in manufacturing engineering research, as well as to produce apparatus to support research efforts in other fields.

Higgins Machine Shop and Project Laboratory

The machine shop in the Higgins Labs consists of three adjacent areas: the Machine Shop (HL004, 600 sq. ft.), the Project Laboratory (HL005, 1600 sq. ft.), and the SAE Project Lab (HL006, 300 sq. ft.). The Machine Shop contains 2 CNC Machine tools (a Haas Tool Room min and a Haas Tool Room Lathe), as well as a surface grinder, 2 DoAll Mills and a DoAll engine lathe as well as a drill press, 2 band saws and assorted hand tools A machinist manages and supports the machine shop and project activities with the assistance of undergraduate PLAs. The Project Laboratory is used primarily for the conduct of capstone design projects requiring a large work and assembly area, such as the SAE Formula Race Car and other SAE projects. Typically, 12 –15 students are involved with the projects in this laboratory throughout the academic year.

In addition to providing space for capstone design projects the project lab also provides space to one of WPI's US First Robotics teams and supports the Robotics Resource Center, as well as being the home of WPI's CollabLab. The CollabLab is a student organization that promotes "maker" culture and collaboration at WPI.

Robotics Laboratory

The Robotics Laboratory, a 1,915 sq. ft. facility, is located on the first floor of the Washburn Building room 108 is equipped with a variety of industrial robots, machine tools and other equipment. The industrial robots, for which the Robotics Laboratory is named, are run primarily during the laboratory sessions of the Industrial Robotics course (ME 4815), and to a lesser extent by undergraduate project groups and graduate researchers. The industrial robots in the laboratory include: one Fanuc LR Mate 200iB, and one Fanuc M-710iC. The Robotics lab houses four of the five entrusted machine tools that are part of WPI's Haas Technical Education Center. The Mill Drill Center (MDC) is a permanent entrustment and has duel pallets so a part can be loaded while the machine is cutting. This machine is frequently used in conjunction with the Fanuc LR Mate. The Haas ST30-Y fully automated 4 axis machining center with an automatic bar feeder. Used in conjunction with the Fanuc ----- and the MDC students can create a fully automated production cell. Both the Haas VM2 and VF4-SS also located in the Robotics Lab are equipped with full 5 axis control systems. We have a Haas fifth axis fixturing system that can be mounted in either machine tool.

CNC Teaching Laboratory

The CNC teaching laboratory is located in the Washburn Shops Room 107 and covers 3,140 sq. ft. The mission of the CNC labs is to support the mission of WPI, by creating, discovering, and conveying knowledge at the frontiers of inquiry in CNC machining and education, as well as linking that new knowledge to applications; help students achieve self-sufficiency in the use of CNC tools and technologies, so they can conceive, design, and create their own CNC machined parts for their projects.

The vision of the CNC labs is to be the premier laboratory for CNC engineering education and research (applied and fundamental) in the world.

In the teaching laboratory we have one Universal Laser Systems VLS60 Laser Cutter, one Makerbot Replicator 2X, 3 Haas MiniMills and 2 Haas SL10s, 3 band saws, two drill presses, a sheet metal shear and bending break as well as assorted hand tools. Attached to each of the MiniMills and SL10s are computer workstations equipped with all of the design and programming software supported on campus and with our instructional tools that have been developed to allow students to train each other.

In addition to the computers located at each of the CNC machine tools in the CNC teaching laboratory and robotics laboratories the facility has two computer classroom spaces one located in 107 with the other in 105. Each of the classroom spaces can be configured to contain between 8 and 12 computer workstations. Each space also has, a conference table, whiteboards, and a ceiling mounted projector that each computer in the space can send its signal to when the spaces are used for project group meetings.

Students working on any of the computer workstations in the facilities have access to the design software packages supported on campus as well as our training materials and several Computer Aided Manufacturing (CAM) software packages including Esprit, MasterCam, and SurfCam.

Metal Additive Manufacturing Lab

At metal additive manufacturing lab, we advance the state-of-the-art in additive manufacturing by working at the intersection of mechanical engineering, materials science, and manufacturing. We specifically use laser powder bed fusion, electron beam powder bed fusion, and wire arc additive manufacturing processes on structural materials such as titanium, nickel, aluminum-based alloys and steels. Our goal is to develop and utilize process-structure-property relations for different processes and materials to achieve desired microstructure and properties. Our lab has an SLM 125 laser powder bed fusion equipment that is suitable for parameter development using small quantities of powders which is especially advantageous for materials development activities. This machine is also equipped with in-situ monitoring capabilities such as melt pool monitoring and laser power monitoring. We also leverage collaborations with other universities, national labs, and companies for access to equipment and complementary skills to achieve our goals.

Metal Processing Institute (MPI)

The Metal Processing Institute (MPI) is an industry-university alliance. Its mission is to design and carry out research projects identified in collaboration with MPI's industrial partners in the field of near and net shape manufacturing. MPI develops knowledge that will help enhance the productivity and competitiveness of the metal processing industry and develops the industry's human resource base through the education of WPI students. Over 90 corporate partners participate in the Institute, and their support helps fund fundamental and applied research that addresses technological barriers facing the industry. MPI is one of WPI's two Institutes with a legacy based on Theory and Practice. MPI houses three centers: the Advanced Casting Research Center (ACRC); the Center for Heat Treating Excellence (CHTE); and the Center for Resource Recovery and Recycling (CR3). The latter is a multi-university center with CSM and KU Leuven.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world.

M.S. in Manufacturing Engineering

For the Master of Science in Manufacturing Engineering, the student is required to complete a minimum of 30 graduate credit hours. The course requirements are presented below. The student will choose between a thesis or Non-Thesis option.

Thesis Option

The student must complete a thesis with a minimum of six graduate credits. Additional thesis credits may substitute for elective courses. All elective courses must be approved by the student's advisor and the Director of Manufacturing Engineering or the Manufacturing Engineering Graduate Committee.

Non-Thesis Option

In addition to the course requirements in the four core areas a Capstone Project is required. This Capstone Project requirement can be met by successful completion of MFE 590 Capstone Project in Manufacturing Engineering or with a three credit Independent Study or Directed Research project in Manufacturing Engineering. All elective courses must be approved by the student's advisor and the Director of Manufacturing Engineering or the Manufacturing Engineering Graduate Committee.

Course Requirements

The Manufacturing Program is designed to focus on four core areas: the manufacturing process and design, materials processing, systems engineering and production/ operations management. These topics are important to the design and control of the factories of the future. The MS in Manufacturing Engineering requires 30 graduate credits. The course requirements are presented below.

Type: Master of Science

Manufacturing Process and Design (4-6 graduate credits)

Item #	Title	Credits
MFE 510	Control and Monitoring of Manufacturing Processes	3
MFE 520/MTE 520/ME 543	Axiomatic Design of Manufacturing Processes	3
MFE 531/ME 5431	Computer Integrated Manufacturing	2
MFE 541/ME 5441	Design for Manufacturability	2

Materials Processing: (5-6 graduate credits)

Item #	Title	Credits
MTE 550	Phase Transformations in Materials	3
MTE 511/ME 5311	Structure and Properties of Engineering Materials	2
MTE 512/ME 531	Properties and Performance of Engineering Materials	2
	Any other MTE 5XXX course with the approval of the program director	

Systems Engineering: (6 graduate credits)

Item #	Title	Credits
SYS 501	Concepts of Systems Engineering	3
SYS 502	Business Practices	3
SYS 540	Introduction to Systems Thinking	3
SD 550	System Dynamics Foundation: Managing Complexity	3

Production/Operations Management: (6 graduate credits)

Item #	Title	Credits
OIE 501	Operations Management	3
OIE 544	Supply Chain Analysis and Design	3
OIE 548	Performance Analytics	3
OIE 553	Global Purchasing and Logistics	3
OIE 558	Designing and Managing Lean Six Sigma Processes	3

Capstone Project: (3 graduate credits)

Item #	Title	Credits
MFE 590	Capstone Project in Manufacturing Engineering	3

Electives: (3-6 graduate credits)

Select from any graduate science or engineering course, with approval of the program director.

Ph.D. in Manufacturing Engineering

The doctoral (Ph.D.) program in MFE is a research degree requiring the following:

All candidates must pass a comprehensive written and oral exam. The written exam may be waived upon the recommendation of the advisor and approval of the MFE program director. All candidates must complete at least one year in residence, present and have a dissertation proposal accepted, the dissertation must be successfully presented and defended.

The dissertation is based on original research. A broad range of research topics is possible, including investigation into the fundamental science on which manufacturing processes are based, material science, manufacturing engineering education, metrology, quality, machine tool dynamics, manufacturing processes, design methodology and production systems, and health systems research.

All WPI requirements for a Ph.D. degree must be met.

Type: Ph.D.

Materials Science and Engineering

Faculty

B. Mishra, Kenneth G. Merriam Professor, Director, Materials & Manufacturing Engineering, Metal Processing Institute; Ph.D., University of Minnesota. Physico-chemical processing of materials; Corrosion science and engineering; Materials Processing, Surface Engineering, Resource Recovery & Recycling, Critical materials extraction; Iron and steelmaking; Alloy development; Thin film coatings.
C. A. Brown, Professor; Director, Surface Metrology Lab; Ph.D., University of Vermont. Surface metrology, multi-scale geometric analyses, axiomatic design, sports engineering, and manufacturing processes.
D. Cote, Assistant Professor, Director, Center for Materials Processing Data (CMPD); Ph.D., Worcester Polytechnic Institute. Computational thermodynamics and kinetics; Phase transformations; Powder metallurgy.
C. Demetry, Professor; Director, Morgan Teaching and Learning Center, Ph.D., Massachusetts Institute of Technology. Materials science and engineering education, nanocrystalline materials and nanocomposites, ceramics, and grain boundaries and interfaces in materials.
D. A. Lados, Milton Prince Higgins II Professor; Director, Integrative Materials Design Center (iMdc); Ph.D.,Worcester Polytechnic Institute. Fatigue, fatigue crack growth, thermo-mechanical fatigue, creep, and fracture of metallic materials – life predictions, computational modeling and ICME, materials/process design and optimization for aerospace, automotive, marine, and military applications; advanced material characterization; additive manufacturing, metal matrix nano–composites, friction stir welding, cold spray technology, powder metallurgy; residual stress; plasticity; fracture mechanics.
Jianyu Liang, Professor, Ph.D., Brown University. Additive manufacturing, nanostructured materials, material processing, material characterization.
M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute. Solidification of Metals, the application of heat, mass and momentum transfer to modeling and solving engineering materials problems, and processing of ceramic materials.
A. Powell, Associate Professor; Ph.D., Massachusetts Institute of Technology. Clean production of materials particularly those used in clean energy, electro chemistry, extractive metallurgy, multiscale modeling of materials process fundamentals, inductrial ecology.
P. Rao, Associate Professor; Ph.D., Stanford University. Solar energy materials, photovoltaic and photoelectrochemical materials, scalable synthesis of nanostructored thin film materials.
S. Shivkumar, Professor; Ph.D., Stevens Institute of Technology. Biomedical materials, plastics, materials processing.
R. D. Sisson Jr., George F. Fuller Professor; Ph.D., Purdue University. Materials process modeling and control, manufacturing engineering, corrosion, and environmental effects on metals and ceramics.
W. Soboyejo, Bernard M. Gordon Dean of Engineering, Professor of Engineering Leadership; Ph.D., Cambridge University. materials science, biomaterials, materials for energy systems and multifunctional materials for sustainable development.
Y. Wang, William Smith Foundation Dean's Professor; Ph.D., University of Windsor (Canada). Lithium ion battery, fuel cell, corrosion and electrochemistry, flow battery.
Y. Zhong, Associate Professor; Ph.D., Pennsylvania State University. Computational Thermodynamics, Integrated materials and processes design (IMPD), Next generation alloys and ceramics.

Program of Study

Materials Science and Engineering (MTE) offers programs leading to a degree of master of science and/or doctor of philosophy.

The master of science in materials science and engineering provides students with an opportunity to study the fundamentals of materials science and state-of-the-art applications in materials engineering and materials processing. The program is designed to build a strong foundation in materials science along with industrial applications in engineering, technology and processing. Both full- and part-time study are available.

Program areas for the doctor of philosophy emphasize the processing-structure-property-performance relationships in metals, ceramics, polymers and composites. Current projects are addressing these issues in fuel cell materials, biopolymers, aluminum and magnesium casting, the heat-treating of steels and aluminum alloys and metal matrix composites.

Well-equipped laboratories within Washburn Shops and Stoddard Laboratories include such facilities as scanning (SEM) and transmission (TEM) electron microscopes, X-ray diffractometer, process simulation equipment, a mechanical testing laboratory including two computer-controlled servohydraulic mechanical testing systems, metalcasting, particulate processing, semisolid processing laboratories, a surface metrology laboratory, a metallographic laboratory, a polymer engineering laboratory with differential scanning calorimeter (DSC), a corrosion laboratory, topographic analysis laboratory and machining force dynamometry. A range of materials processing, fastening, joining, welding, machining, casting and heat treating facilities is also available.

Admission Requirements

The program is designed for college graduates with engineering, mathematics or science degrees. Some undergraduate courses may be required to improve the student's background in materials science and engineering. For further information, see Admission Information.

For admission in to BS/MS program, Students should apply during their junior or senior year. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher. A grade of B or better is required for any course to be counted toward both degrees. Waiver of any of these requirements must be approved by the Materials Science and Engineering Graduate Committee, which will exercise its discretion in handling any extenuating circumstances or problems.

Materials Science and Engineering Laboratories and Research Centers

Electrochemical Energy Laboratory

The electrochemical energy laboratory is equipped for analyzing a variety of electrochemical reactions. Examples of these reactions include electrolysis of metal salts for primary metal production, lithium ion transport in lithium ion batteries and reactions involved in colloidal flow battery suspensions. The equipment includes three different electrochemical analyzers (Bio-logic electrochemical tester with 10 channels, Newware Battery testing system, Arbin BT2043 with MitsPro4.0 System), and a two-person MBRAUN Glovebox. Additionally several furnaces, oven, high energy ball mill, overhead stirrer, spin coater and a hydraulic press are available for electrode preparation. The lab also includes a Shutte Buffalo W-6-H hammermill for recycling related projects.

Integrative Materials Design Center (iMdc)

iMdc is a WPI-based research center dedicated to advancing the state-of-the-art-and-practice in sustainable materials-process-component design and manufacturing for high-performance, reliability, and recyclability through knowledge creation and dissemination, and through education.

iMdc is formed through an industry-government-university alliance, and its program is built in direct collaboration, and with active participation and insight from its industrial and government partners. The center is conducting fundamental research, which addresses well-identified industrial applications of general interest and relevance to the manufacturing sector.
The overarching objective of the iMdc's research portfolio is to prevent failure and increase high–performance and reliability of high-integrity structures through:

- Exploring and advancing the fundamental and practical understanding of a wide range of multi-scale metallic and composite materials and their respective processes
- Developing new and optimized materials and processing practices, including recycling as a design factor
- Establishing knowledge-based microstructure-properties-performance relationships
- Investigating the impact of increased utilization of recycled materials in high-performance materials and applications
- Providing practical and integrated design and computational (ICME) methods and tools
- Identifying and pursuing implementation venues for the developed materials, processes, and design methodologies

Industrial and government partners review and provide insight and guidance to the research programs, bring industrial perspective, and assist in identifying strategies for the implementation of the developments in the industry. This setting provides a platform for creating knowledge in a well-defined context while being able to disseminate it and witness its implementation and impact in/on actual industrial applications.

Materials Characterization Laboratory

The Materials Characterization Laboratory (MCL) is an analytical user facility, which serves the materials community at WPI, offering a range of analytical techniques and support services. Licensed users have 24/7 access to instruments including JEOL 7000F field-emission gun scanning electron microscope, JEOL 100CXII transmission electron microscope, PANalytical Empyrean x-ray diffractometer, Spectro MAXx LMX04 Spectrometer, Agilent Nanoindenter, Clark CM-400AT microhardness indenter, Shimazu HMV-2000 Microhardness tester, Buehler Microhardness tester, Rockwell hardness testers, and more than 10 grinding and polishing machines. The MCL is also open to researchers from other universities and local industries.

Metal Processing Institute (MPI)

The Metal Processing Institute (MPI) is an industry-university alliance dedicated to advancing available technology to the metal processing and materials recovery and recycling industries. Students, professors and more than 90 industry partners work together on research projects that address technological barriers facing industry – making member businesses more competitive and productive.
MPI offers educational opportunities and corporate resources to undergraduate and graduate students. They include:

- International exchanges and internships with several leading universities in Europe and Asia.
- Graduate internship programs leading to a master's or doctoral degree, where the research is carried out at the industrial site.
- MPI's research programs are managed by three distinct research centers:
- Advanced Casting Research Center (ACRC) – more information below.
- Center for Heat Treating Excellence (CHTE) – more information below.
- Center for Resource Recovery and Recycling (CR3) – more information below.

For further information please visit the MPI offices on the third floor of Washburn, Room 326. Our visit our website: http://wpi.edu/+mpi

Center for Heat Treating Excellence (CHTE)

At the Center for Heat Treating Excel- lence (CHTE) students get to work with industry leaders and WPI faculty to solve business challenges and improve manufac- turing processes through applied research .

Students will have the opportunity to work with over 20 corporate members from various parts of the heat treating industry – commercial heat treaters, captive heat treaters, suppliers and manufacturers.

Project opportunities, industrial internships, co-op opportunities and summer employment are available through CHTE. http://wpi.edu/+chte

Center for Resource Recovery and Recycling (CR3)

In nature, nothing is wasted. The Center for Resource Recovery & Recycling (CR3) is the premiere industry-university collaborative that works towards taking the waste from one process and utilizing it in another, establishing a closed loop system – just as nature would. CR3's mission is to be the ultimate resource in material sustainability.

Students who work with CR3 will work with industry leaders on technological advancements that recover and recycle materials from initial product design, through manufacture to end-of-life disposition. The end result: enhanced environmental conservation, and im proved energy and cost savings.

CR3 is an Industry and University Center (I/UCRC) and is supported by the National Science Foundation (NSF). Partner universities include Colorado School of Mines and KU Leuven, Belgium. For more information: https://wpi.edu/+cr3

Mineral Processing Laboratory

The Mineral Processing Lab consists of state of the art facilities to carry out physical separation, hydro, and pyro-metallurgical operations to separate and recover base metals and critical elements from waste streams and primary ores.

The lab consists of an attrition mill for primary size reduction and grinding of feed material. The mill runs in both dry and wet media at RPM of 100 to 500 with grinding media ranging from 1/8" to 2". Furthermore, to study the particle size distribution after grinding, the lab consists of a Sieve Shaker (RX-29) to classify particles ranging from 45 to 600 microns.

The Frantz Magnetic Barrier Laboratory Separator (LB-1) separates mineral components according to their paramagnetic and diamagnetic susceptibility. With optimized orientation of inclined chute and magnetic system, the desired relationship between gravitational and magnetic forces can be achieved for effective separation.

The lab also consists of a custom-built wet drum magnetic separator (Steinert make). Rotating magnetic drums separate the magnetic particles from slurry and are further scraped off from the drum surface by separating splitter to obtain highly concentrated magnetic concentrate.

Heat treatment experiments are performed in a controlled atmosphere furnace (Carbolite Gero, HTMA 6/28) with a maximum temperature of 600 °C and 95 L volume, and 180 L laboratory oven (Fisherbrand) for heating of samples in 50 – 250 °C range.

The large-scale leaching setup consists of two 100 L stainless steel (SS316) tank along with an overhead electric motor with shaft for mixing of slurry. The filtration system consists of a settling tank, bag filter with a cut off size of 5 microns, and a pressure filter for filtration of particles above 1 micron and a stainless-steel hydro cyclone with 7 to 10-micron separation efficiency. Gamry Reference 600 is used to recover elements with the electro-winning approach and study electrochemical corrosion and check cyclic voltammetry.

NanoEnergy Laboratory

Research in the NanoEnergy Lab targets the synthesis and study of ordered nanomaterials for energy conversion applications, particularly for converting solar energy to electrical or chemical energy. The goal is to use nanostructuring and scalable, economical synthesis methods to dramatically improve the energy conversion efficiency of earth-abundant, low-cost materials.

Projects in the NanoEnergy Lab focus on:

- Flame-synthesis of complex, hierarchical, ordered nanomaterials
- Design, synthesis and characterization of nanostructured materials for solar energy conversion (photovoltaic and photoelectrochemical)

Nanomaterials synthesis equipment in the NanoEnergy lab includes vapor deposition (flat-flame burner and multi-zone tube furnace), hydrothermal synthesis reactors, solution deposition (fume hood, spin-coater), and various furnaces for annealing materials. Light sources, integrating spheres, spectrometers, a potentiostat, electrochemical cells and chemical sensors are available for the characterization of optical, electronic and electrochemical properties of materials.

The NanoEnergy Lab is located in Rooms 4916 and 4918, 50 Prescott St. (Gateway Park II). For further information, please see nanoenergy.wpi.edu.

Nanomaterials and Nanomanufacturing Laboratory

This laboratory is well-equipped for advanced research in controlled nanofabrications and nanomanufacturing of carbon nanotubes, magnetized nanotubes, semiconducting, superconducting, magnetic, metallic arrays of nanowires and quantum dots. Nanomaterials fabrication and engineering will be carried out in this laboratory by different means, such as PVD (physical vapor deposition), CVD (chemical vapor deposition), PECVD (plasma enhanced CVD), RIE (reactive ion etching), ICP etching (induced coupled plasma), etc. Material property characterizations will be conducted, including optic, electronic, and magnetic property measurements. Nanostructured device design, implementation, and test will also be carried out in this lab.

Polymer Laboratory

This laboratory is used for the synthesis, processing and testing of plastics. The equipment includes: thermal analysis machines Perkin Elmer DSC 4, DSC 7, DTA 1400 and TGA 7; single-screw table-top extruder; injection molding facilities; polymer synthesis apparatus; oil bath furnaces; heat treating ovens; and foam processing and testing devices.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world.

B.S./M.S. in Materials Science and Engineering

The student is required to complete a minimum of 30 graduate credit hours; a maximum of 12 credit hours may be double counted toward both the undergraduate and graduate degrees. Requirements include MTE 511 and MTE 512 and at least four of the following courses: MTE 526, MTE 532, MTE 540, MTE 550, MTE 561. For the remaining credits, the student may choose additional MTE or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. Satisfactory participation in the materials engineering seminar (MTE 580) is also required for all full-time students.

The student must complete a capstone project, or equivalent, for a minimum of three credits and a maximum of six credits. The project must demonstrate the ability to design, implement, and complete an independent professional project.

Type: B.S./M.S.

M.S. in Materials Science and Engineering

For the master of science in materials science and engineering, the student is required to complete a minimum of 30 graduate credit hours. Requirements include MTE 511 and MTE 512 and at least 4 of the following courses: MTE 526, MTE 532, MTE 540, MTE 550, MTE 561. For the remaining credits, the student may choose between a thesis or coursework option and Directed Research.

Thesis Option

The student must complete a thesis with a minimum of 6 graduate credits. Additional thesis credits may substitute for course electives. The remaining graduate credits must consist of additional MTE or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All courses must be approved by the student's advisor and the Materials Graduate Committee.

Non Thesis Option

The student must complete a three credit capstone project or equivalent that demonstrates the ability to design, implement, and complete an independent professional project. The remaining graduate credits must consist of additional MTE or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All courses must be approved by the student's advisor and the Materials Graduate Committee.

Satisfactory participation in the materials engineering seminar (MTE 580) is also required for all full-time students. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher. Waiver of any of these requirements must be approved by the Materials Science and Engineering Graduate Committee, which will exercise its discretion in handling any extenuating circumstances or problems.

Examples of Typical Program

- Materials engineering core courses—18 credits
- Electives—6 credits
- Thesis—6 credits
- Total—30 credits

Type: Master of Science

Ph.D. in Materials Science and Engineering

The number of course credits required for the doctor of philosophy degree, above those for the master of science, is not specified precisely. For planning purposes, the student should consider a total of 21 to 30 course credits. The remainder of the work will be in research and independent study. The total combination of research and coursework required will not be less than 60 credits beyond the master of science degree or not less than 90 credits beyond the bachelor's degree.

Admission to candidacy will be granted only after the student has satisfactorily passed the Materials Engineering Doctoral Qualifying/ Comprehensive Examination (MEDQE). The purpose of this exam is to determine if the student's breadth and depth of understanding of the fundamental areas of materials engineering is adequate to conduct independent research and successfully complete a Ph.D. dissertation.

The MEDQE consists of both written and oral components. The written exam must be successfully completed before the oral exam can be taken. The oral exam is usually given within two months of the completion of the written exam. The MEDQE is offered at least one time each year.

A member of the materials science and engineering faculty will be appointed to be the chairperson of the MEDQE Committee. This person should not be the student's Ph.D. thesis advisor; but that advisor may be a member of the MEDQE Committee. Others on the committee should be the writers of the four sections of the examinations and any other faculty selected by the chairperson. Faculty from other departments at WPI or other colleges/universities, as well as experts from industry, may be asked to participate in this examination if the materials engineering faculty deems that it is appropriate.

At least one year prior to completion of the Ph.D. dissertation, the student must present a formal seminar to the public describing the proposed dissertation research project. This Ph.D. research proposal will be presented after admission to candidacy.

Type: Ph.D.

Mathematical Sciences

Faculty

S. Olson, Professor and Head; Ph.D., North Carolina State University 2008. Mathematical biology, computational biofluids, scientific computing.
J. Abraham, Professor of Practice and Actuarial Mathematics Coordinator; Fellow, Society of Actuaries, 1991; B.S., University of Iowa, 1980.
A. Arnold, Assistant Professor; Ph.D., Case Western Reserve University, 2014. Mathematical biology, Bayesian inference, parameter estimation in biological systems.
F. Bernardi, Assistant Professor; Ph.D., University of North Carolina at Chapel Hill, 2018. Small-scale fluid mechanics and microfluidics, in particular modeling particle transport and water filtration systems.
M. Blais, Teaching Professor, Coordinator of Professional Science Master's Programs and Associate Department Head; Ph.D., Cornell University, 2005. Mathematical finance.
L. Capogna, Professor; Ph.D., Purdue University, 1996. Partial differential equations.
J. D. Fehribach, Professor; Ph.D., Duke University, 1985. Partial differential equations and scientific computing, free and moving boundary problems (crystal growth), nonequilibrium thermodynamics and averaging (molten carbonate fuel cells).
J. Goulet, Teaching Professor and Coordinator, Master of Mathematics for Educators Program; Ph.D., Rensselaer Polytechnic Institute, 1976. Applications of linear algebra, cross departmental course development, project development, K-12 relations with colleges, mathematics of digital and analog sound and music.
A. C. Heinricher, Professor; Ph.D., Carnegie Mellon University, 1986. Applied probability, stochastic processes and optimal control theory.
M. Humi, Professor; Ph.D., Weizmann Institute of Science, 1969. Mathematical physics, applied mathematics and modeling, Lie groups, differential equations, numerical analysis, turbulence and chaos.
M. Johnson, Teaching Associate Professor; Ph.D., Clark University 2012. Industrial organization, game theory.
C. J. Larsen, Professor; Ph.D., Carnegie Mellon University, 1996. Variational problems from applications such as optimal design, fracture mechanics, and image segmentation, calculus of variations, partial differential equations, geometric measure theory, analysis of free boundaries and free discontinuity sets.
R. Y. Lui, Professor; Ph.D., University of Minnesota, 1981. Mathematical biology, partial differential equations.
K. A. Lurie, Professor; Ph.D., 1964, D.Sc., 1972, A. F. Ioffe Physical-Technical Institute, Academy of Sciences of the USSR, Russia. Control theory for distributed parameter systems, optimization and nonconvex variational calculus, optimal design.
W. J. Martin, Professor; Ph.D., University of Waterloo, 1992. Algebraic combinatorics, applied combinatorics.
U. Mosco, H. J. Gay Professor; Libera Docenza, University of Rome, 1967. Partial differential equations, convex analysis, optimal control, variational calculus, fractals.
B. Nandram, Professor; Ph.D., University of Iowa, 1989. Survey sampling theory and methods, Bayes and empirical Bayes theory and methods, categorical data analysis.
P. O'Cathain, Assistant Professor; Ph.D., National University of Ireland, Galway, 2012. Combinatorics, algebra and compressed sensing.
R. C. Paffenroth, Associate Professor; Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.
B. Peiris, Associate Teaching Professor, Ph.D., Southern Illinois University, Carbondale, 2014. Bayesian Statistics, order restricted inference, meta-analysis.
G. Peng, Assistant Professor; Ph.D., Purdue University, 2014. Partial differential equations with a focus on applications to the sciences.
B. Posterro, Teaching Associate Professor; M.S., Financial Mathematics, Worcester Polytechnic Institute, 2010, M.S. Applied Mathematics, Worcester Polytechnic Institute, 2000.
A. Sales, Assistant Professor; Ph.D., University of Michigan, 2013. Methods for causal inference using administrative or high-dimensional data, especially in education.
M. Sarkis, Professor; Ph.D., Courant Institute of Mathematical Sciences, 1994. Domain decomposition methods, numerical analysis, parallel computing, computational fluid dynamics, preconditioned iterative methods for linear and non-linear problems, numerical partial differential equations, mixed and non-conforming finite methods, overlapping non-matching grids, mortar finite elements, eigenvalue solvers, aeroelasticity, porous media reservoir modeling.
B. Servatius, Professor; Ph.D., Syracuse University, 1987. Combinatorics, matroid and graph theory, structural topology, geometry, history and philosophy of

mathematics.
S. Sturm, Associate Professor; Ph.D. TU Berlin 2010. Mathematical finance: stochastic volatility, optimal portfolio problems, systemic risk; stochastic analysis: backward stochastic differential equations, large deviations, Malliavin calculus.
D. Tang, Professor; Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.
B. S. Tilley, Professor; Ph.D., Northwestern University, 1994. Free-boundary problems in continuum mechanics, interfacial fluid dynamics, viscous flows, partial differential equations, mathematical modeling, asymptotic methods.
B. Vernescu, Professor; Ph.D., Institute of Mathematics, Bucharest, Romania, 1989. Partial differential equations, phase transitions and free-boundaries, viscous flow in porous media, asymptotic methods and homogenization.
D. Volkov, Professor; Ph.D., Rutgers University, 2001. Electromagnetic waves, inverse problems, wave propagation in waveguides and in periodic structures, electrified fluid jets.
S. Walcott, Associate Professor; Ph.D., Cornell University. Mathematical and physical biology.
F. Wang, Associate Professor; Ph.D., UNC Chapel Hill, 2019. Time series analysis, spatial statistics/spatial econometrics, financial econometrics, and risk management.
G. Wang, Associate Professor; Ph.D., Boston University, 2013. Stochastic control, mathematical finance, stochastic analysis, applied probability.
S. Weekes, Professor; Ph.D., University of Michigan, 1995. Numerical analysis, computational fluid dynamics, porous media flow, hyperbolic conservation laws, shock capturing schemes.
M. Wu, Assistant Professor; Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.
Z. Wu, Professor; Ph.D., Yale University, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.
V. Yakovlev, Associate Research Professor; Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences, 1991. Antennas for MW and MMW communications, electromagnetic fields in transmission lines and along media interfaces, control and optimization of electromagnetic and temperature fields in microwave thermal processing, issues in modeling of microwave heating, computational electromagnetics with neural networks, numerical methods, algorithms and CAD tools for RF, MW and MMW components and subsystems.
Z. Zhang, Associate Professor; Ph.D., Brown University, 2014, Shanghai University, 2011. Numerical analysis, scientific computing, computational and applied mathematics, uncertainty qualification.
J. Zou, Associate Professor; Ph.D., University of Connecticut, 2009. Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Emeritus

P. Christopher, Professor
P. W. Davis, Professor
W. J. Hardell, Professor
J. J. Malone, Professor
B. C. McQuarrie, Professor
W. B. Miller, Professor
J. Petrucelli, Professor
D. Vermes, Professor
H. Walker, Professor

Research Interests

Active areas of research in the Mathematical Sciences Department include applied and computational mathematics, industrial mathematics, applied statistics, scientific computing, numerical analysis, ordinary and partial differential equations, non-linear analysis, electric power systems, control theory, optimal design, composite materials, homogenization, computational fluid dynamics, biofluids, dynamical systems, free and moving boundary problems, porous media modeling, turbulence and chaos, mathematical physics, mathematical biology, operations research, linear and nonlinear programming, discrete mathematics, graph theory, group theory, linear algebra, combinatorics, applied probability, stochastic processes, time series analysis, Bayesian statistics, Bayesian computation, survey research methodology, categorical data analysis, Monte Carlo methodology, statistical computing, survival analysis and model selection.

Programs of Study

The Mathematical Sciences Department offers four programs leading to the degree of master of science, a combined B.S./Master's program, a program leading to the degree of master of mathematics for educators, and a program leading to the degree of doctor of philosophy.

Admission Requirements

A basic knowledge of undergraduate analysis, linear algebra and differential equations is assumed for applicants to the master's programs in applied mathematics and industrial mathematics. A strong background in mathematics, which should include courses in undergraduate analysis and linear algebra, is assumed for applicants to the master's program in financial mathematics. Typically, an entering student in the master of science in applied statistics program will have an undergraduate major in the mathematical sciences, engineering or a physical science; however, individuals with other backgrounds will be considered. In any case, an applicant will need a strong background in mathematics, which should include courses in undergraduate analysis and probability. Students with serious deficiencies may be required to correct them on a noncredit basis. Applicants to the Mathematical Sciences Ph.D. Program should submit GRE Mathematics Subject Test scores if possible; an applicant who finds it difficult to submit a score is welcome to contact the Mathematical Sciences Department Graduate Admissions Committee (ma-questions@wpi.edu) to discuss the applicant's situation.

For the applicants to the Ph.D. Program in Statistics, strong background of undergraduate analysis, linear algebra and probability is assumed; the GRE Mathematics Subject Test is recommended but not required.
Candidates for the master of mathematics for educators degree must have a bachelor's degree and must possess a background equivalent to at least a minor in mathematics, including calculus, linear algebra, and statistics. Students are encouraged to enroll in courses on an ad hoc basis without official program admission. However, (at most) four such courses may be taken prior to admission.

Mathematical Sciences Computer Facilities

The Mathematical Sciences Department makes up-to-date computing equipment available for use by students in its programs.
Current facilities include a mixed environment of approximately 85 Windows, Linux/Unix and Macintosh workstations utilizing the latest in single- and dual-processor 32 and 64 bit technology as well as 4 Bloomberg terminals. Access is available to our supercomputer, a 16 CPU SGI Altix 350. The Mathematical Sciences Department also has 3 state-of-the-art computer labs, one each dedicated to the Calculus, Statistics, and Financial Mathematics programs.
The department is continually adding new resources to give our faculty and students the tools they need as they advance in their research and studies.

Center for Industrial Mathematics and Statistics (CIMS)

www.wpi.edu/+CIMS
The Center for Industrial Mathematics and Statistics was established in 1997 to foster partnerships between the university and industry, business and government in mathematics and statistics research.

The problems facing business and industry are growing ever more complex, and their solutions often involve sophisticated mathematics. The faculty members and students associated with CIMS have the expertise to address today's complex problems and provide solutions that use relevant mathematics and statistics.

The Center offers undergraduates and graduate students the opportunity to gain real-world experience in the corporate world through projects and internships that make them more competitive in today's job market. In addition, it helps companies address their needs for mathematical solutions and enhances their technological competitiveness.

The industrial projects in mathematics and statistics offered by CIMS provide a unique education for successful careers in industry, business and higher education.

B.S./M.S. in Mathematical Sciences

This program allows a student to work concurrently toward bachelor and master of science degrees in applied mathematics, applied statistics, financial mathematics and industrial mathematics.

Degree Requirements

Credits from no more than four courses may be counted toward both the undergraduate and graduate degrees. All of these courses must be 4000-level or above, and at least one must be a graduate course. Three of them must be beyond the 7 units of mathematics required for the B.S. degree. Additionally, students are advised that all requirements of a particular master's program must be satisfied in order to receive the degree, and these courses should be selected accordingly.

Acceptance into the program means that the candidate is qualified for graduate school and signifies approval of the four courses to be counted for credit toward both degrees. However, in order to obtain both undergraduate and graduate credit for these courses, grades of B or better have to be obtained.

Type: B.S./M.S.

Master of Mathematics for Educators (MME)

This is an evening and/or online program designed primarily for secondary school mathematics teachers. Courses offer a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics, while also including the study of modern applications. Additionally, students develop materials, based on coursework, which may be used in their classes. Technology is introduced when possible to give students exposure for future consideration. Examples include Geometer's Sketchpad; Maple for algebra, calculus and graphics; Matlab for analysis of sound and music; and the TI CBL for motion and heat.

Degree Requirements

Candidates for the Master of Mathematics for educators must successfully complete 30 credit hours of graduate study, including a 6-credit-hour project (see MME 592, MME 594, MME 596). This project will typically consist of a classroom study within the context of a secondary mathematics course and will be advised by faculty in the Mathematical Sciences Department. Typically, a student will enroll in 4 credit hours per semester during the fall and spring, with the remaining credit hours taken in the summer.

Students may complete the degree in as little as slightly over two years by taking two courses per semester, 3 semesters per year, and doing a project. However, the program can accommodate other completion schedules as well. The MME degree may be used to satisfy the Massachusetts Professional License requirement, provided the person holds an Initial License.

Type: Master of Mathematics for Educators (MME)

M.S. in Applied Mathematics Program

This program gives students a broad background in mathematics, placing an emphasis on areas with the highest demand in applications: numerical methods and scientific computation, mathematical modeling, discrete mathematics, mathematical materials science, optimization and operations research. In addition to these advanced areas of specialization, students are encouraged to acquire breadth by choosing elective courses in other fields that complement their studies in applied mathematics. Students have a choice of completing their master's thesis or project in cooperation with one of the department's established industrial partners. The program provides a suitable foundation for the pursuit of a Ph.D. degree in applied mathematics or a related field, or for a career in industry immediately after graduation.

Degree Requirements

The master's program in Applied Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. The student's program must include MA 502, MA 503, and MA 510 and at least four additional MA numbered graduate courses other than MA 500, MA 501, MA 511, and MA 517.

In addition, students are required to complete a Capstone Experience, which can be satisfied by one of the following options:

1. A six credit master's thesis.
2. A three to six credit master's project.
3. A three credit master's practicum.
4. A three credit research review report or research proposal.
5. A master's exam.

The master's thesis is an original piece of mathematical research work which focuses on advancing the state of the mathematical art. The master's project consists of a creative application of mathematics to a real-world problem. It focuses on problem definition and solution using mathematical tools. The master's practicum requires a student to demonstrate the integration of advanced mathematical concepts and methods into professional practice. This could be done through a summer internship in industry or an applied research laboratory.

The remaining courses may be chosen from the graduate courses or independent studies of the Mathematical Sciences Department. Up to six credits of upper-level (i.e., 4000-level) undergraduate courses in mathematics or another department may be taken for graduate credit, subject to the approval of the program coordinator. Candidates are required to successfully complete the graduate seminar MA 557.

Type: Master of Science

M.S. in Applied Statistics Program

This program gives graduates the knowledge and experience to tackle problems of statistical design, analysis and control likely to be encountered in business, industry or academia. The program is designed to acquaint students with the theory underlying modern statistical methods, to provide breadth in diverse areas of statistics and to give students practical experience through extensive application of statistical theory to real problems.

Through the selection of elective courses, the student may choose a program with an industrial emphasis or one with a more theoretical emphasis.

Degree Requirements

The master's program in Applied Statistics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. Courses taken must include MA 540, MA 541, MA 546, MA 547, 3 credits of MA 559 and at least three additional departmental statistics offerings: MA 509 and courses numbered 542 through 556. Students who can demonstrate a legitimate conflict in scheduling MA 559 will be assigned an alternative activity by the program coordinator. In addition the student must complete a Capstone Experience, which can be satisfied by one of the following options:

1. A six credit master's thesis.
2. A three to six credit master's project.
3. A three credit master's practicum.
4. A three credit research review report or research proposal.
5. A master's exam.

Upper-level undergraduate courses may be taken for graduate credit subject to the approval of the departmental Graduate Committee.

Type: Master of Science

Master of Science in Mathematics for Educators (MMED)

The Master of Science in Mathematics for Educators is designed specifically for middle school, high school and junior college in-service educators. The emphasis of the program is put on mathematics content coursework combined with courses in assessment and evaluation theory and a culminating project designed by the participant. The mathematics content courses, designed for educators, offer teachers a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics, while also including the study of modern applications. In these courses, participants have the opportunity to develop materials, based on coursework, which may be used in their classes. Throughout the courses, technology is introduced whenever possible to help educators become familiar with the options available for use in the classroom. Examples of this include Geometer's Sketchpad and the TI CBL for motion and heat. This combination of content courses, assessment and evaluation theory courses, and a final project are perfect for educators looking for a program that emphasizes mathematics and supports educators in learning how to better evaluate their effectiveness in the classroom. For information about admissions and requirements, see the listing under STEM for Educators.

Degree Requirements

For a complete overview of degree requirements, please see STEM for Educators.

Type: Master of Science

Professional Master of Science in Financial Mathematics Program

This program offers an efficient, practice-oriented track to prepare students for quantitative careers in the financial industry, including banks, insurance companies, and investment and securities firms. The program gives students a solid background and sufficient breadth in the mathematical and statistical foundations needed to understand the cutting edge techniques of today and to keep up with future developments in this rapidly evolving area over the span of their careers. It also equips students with expertise in quantitative financial modeling and the computational methods and skills that are used to implement the models. The mathematical knowledge is complemented by studies in financial management, information technology and/or computer science.

The bridge from the academic environment to the professional workplace is provided by a professional master's project that involves the solution of a concrete, real-world problem directly originating in the financial industry. Students are encouraged to complete summer internships at financial firms. The department may help students to find suitable financial internships through the industrial connections of faculty affiliated with the Center for Industrial Mathematics and Statistics. Graduates of the program are expected to start or advance their professional careers in such areas as financial product development and pricing, risk management, investment decision support and portfolio management.

Degree Requirements

The master's program in Financial Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. The curriculum consists of the following components:

Type: Master of Science

1. 6 credits from required foundation courses:

Item #	Title	Credits
	MA 529 or MA 503	
	MA 528 or MA 540	

2. 12 credits from core financial mathematics courses:

Item #	Title	Credits
MA 571	Financial Mathematics I	3
MA 572	Financial Mathematics II	3
MA 573	Computational Methods of Financial Mathematics	3
MA 574	Portfolio Valuation and Risk Management	3
MA 575	Market and Credit Risk Models and Management	3

3. 3 credits chosen from Mathematical Sciences graduate courses MA 502-590.

B.S./M.S. students can count undergraduate courses MA 4213 Risk Theory, MA 4214 Survival Models, MA 4235 Mathematical Optimization, MA 4237 Probabilistic Methods in Operations Research, MA 4451 Boundary Value Problems, MA 4473 Partial Differential Equations, MA 4632 Probability and Mathematical Statistics II towards electives.

6 credit block in one of the following complementary areas outside of the Mathematical Sciences Department: Financial Management, Information Technology, or Computer Science.

Students with a degree or substantial work experience in one of the above complementary areas can substitute them with other courses subject to prior approval by the graduate committee

B.S./M.S. students can count suitable undergraduate courses towards the complementary area requirement according the number of credits of the corresponding graduate courses

2 of the complementary area credits can be earned by taking MA 579 Financial Programming Workshop

Capstone Project, which may be satisfied by one of the following options:

1. A three to six credit master's project.
2. A three credit master's practicum.
3. A three credit capstone course in financial mathematics.

The master's project consists of a creative application of mathematics to a real-world problem originating in the financial industry. It focuses on problem definition and solution using mathematical tools. The master's practicum requires a student to demonstrate the integration of advanced mathematical concepts and methods into professional practice. This could be done through an approved summer internship in industry or an applied research laboratory. The capstone course in financial mathematics can be chosen from MA 572, MA 573, MA 574, or MA 575 and will be an enhanced version of the course with extra work assigned. Prior to the start of the capstone course, a student seeking to use the course to satisfy the requirement must declare this intention to the professor of the course.

6. MA 562A and MA 562B Professional Master's Seminar (for no credit)

Professional Master of Science in Industrial Mathematics Program

This is a practice-oriented program that prepares students for successful careers in industry. The graduates are expected to be generalized problem-solvers, capable of moving from task to task within an organization. In industry, mathematicians need not only the standard mathematical and statistical modeling and computational tools, but also knowledge within other areas of science or engineering. This program aims at developing the analytical, modeling and computational skills needed by mathematicians who work in industrial environments. It also provides the breadth required by industrial multidisciplinary team environments through courses in one area of science or engineering, e.g., physics, computer science, mechanical engineering, and electrical and computer engineering.

The connection between academic training and industrial experience is provided by an industrial professional master's project that involves the solution of a concrete, real-world problem originating in industry. The department, through the industrial connections of the faculty affiliated with the Center for Industrial Mathematics and Statistics, may help students identify and select suitable industrial internships. Graduates of the program are expected to start or advance their professional careers in industry.

Degree Requirements

The master's program in Industrial Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. Students must complete four foundation courses: MA 503, MA 510 and two courses out of MA 508, MA 509, MA 529 and MA 530. Students must also complete a 12-credit-hour module composed of two courses within the department and a sequence of two courses from one graduate program outside the Mathematical Sciences Department. The department offers a wide selection of modules to suit students' interest and expertise.

In addition, students are required to complete a 3-credit-hour elective from the Mathematical Sciences Department and a 3-credit-hour master's project on a problem originating from industry. Candidates are required to successfully complete the Professional Master's Seminars MA 562A and MA 562B. The Plan of Study and the project topic require prior approval by the departmental Graduate Committee.

Examples of Modules for the M.S. Degree in Industrial Mathematics

The courses comprising the 12-credit module should form a coherent sequence that provides exposure to an area outside of mathematics and statistics, providing at the same time the mathematical tools required by that particular area. Examples of typical modules are:

- Dynamics and control module—MA 512, MA 540, ME 5220, 5221, 5222, 5223;
- Materials module—MA 512, MA 526, and ME 5311;
- Fluid dynamics module—MA 512, MA 526, ME 511 and ME 5101, 5102, 5103;
- Biomedical engineering module—MA 512, MA 526, BME/ME 550 and BME/ME 552;
- Machine learning module—MA 540, MA 541, CS 509 and CS 539;
- Cryptography module—MA 533, MA 514, CS 503 and ECE 578.

Type: Master of Science

Ph.D. in Mathematical Sciences

The goal of this program is to produce active and creative problem solvers, capable of contributing in academic and industrial environments. One distinguishing feature of this program is an optional Ph.D. project to be completed under the guidance of an external sponsor, e.g., from industry or a national research center. The intention of this project is to connect theoretical knowledge with relevant applications and to improve skills in applying and communicating mathematics.

Degree Requirements

The course of study leading to the doctor of philosophy in mathematical science and the doctor of philosophy in statistics requires the completion of at least 90 credit hours beyond the bachelor's degree or at least 60 credit hours beyond the master's degree, as follows:

General Courses (credited for students with master's degrees)	30 credits
Research Preparation Phase	**24-30 credits**
Research-Related Courses or Independent Studies	9-18 credits
Ph.D. Project	1-9 credits
Extra-Departmental Studies	6 credits
Dissertation Research	at least 30 credits

A brief description of other Ph.D. program requirements follows below. For further details, students are advised to consult the document Ph.D. Program Requirements and Administrative Rules for the Department of Mathematical Sciences, available from the departmental graduate secretary.
Within a full-time student's first semester of study (second semester for part-time students), a Plan of Study leading to the Ph.D. degree must be submitted to the departmental Graduate Committee for review and approval. The Plan of Study may subsequently be modified with review by the departmental Graduate Committee.

Extra-Departmental Studies Requirement

A student must complete at least six semester hours of courses, 500 level or higher, in WPI departments other than the Mathematical Sciences Department.
General Comprehensive Examination

A student must pass the general comprehensive examination (GCE) in order to become a Ph.D. candidate. The purpose of the GCE is to determine whether a student possesses the fundamental knowledge and skills necessary for study and research at the Ph.D. level. It is a written examination offered three times a year, once each in

January, May, and August. A student must pass by January of their second year if they enter in the fall, and May of their second year if they enter in the spring.

Mathematical Sciences Ph.D. Project

A student may complete a Ph.D. project involving a problem originating with a sponsor external to the department. The purposes of the project are to broaden perspectives on the relevance and applications of mathematics and to improve skills in communicating mathematics and formulating and solving mathematical problems. Students are encouraged to work with industrial sponsors on problems involving applications of the mathematical sciences. Each Ph.D. project requires prior approval by the project advisor, the external sponsor, and the departmental Graduate Committee.

Ph.D. Preliminary Examination

Successful completion of the preliminary examination is required before a student can register for dissertation research credits. The purpose of the preliminary examination is to determine whether a student's understanding of advanced areas of mathematics is adequate to conduct independent research and successfully complete a dissertation. The preliminary examination consists of both written and oral parts. A full-time student must make the first attempt by the end of his or her third year (sixth year for part-time students) in the Ph.D. program.

Ph.D. Dissertation

The Ph.D. dissertation is a significant work of original research conducted under the supervision of a dissertation advisor, who is normally a member of the departmental faculty. The dissertation advisor chairs the student's dissertation committee, which consists of at least five members, including one recognized expert external to the department, and which must be approved by the departmental Graduate Committee. At least six months prior to completion of the dissertation, a student must submit a written dissertation proposal and present a public seminar on the research plan described in the proposal. The proposal must be approved by the dissertation committee. Upon completion of the dissertation and other program requirements, the student presents the dissertation to the dissertation committee and to the general community in a public oral defense. The dissertation committee determines whether the dissertation is acceptable.

Unsatisfactory Progress

If the aforementioned milestones are not met, then the student must petition the graduate program committee to request extra time to meet the requirements or the student will be no longer be part of the Ph.D. program as of the following semester.

Type: Ph.D.

Ph.D. in Statistics

The overall objective is to create a highly competitive program that produces future scholars and leaders in Statistics. The program will provide rigorous and comprehensive training in mathematics, statistics and related areas, as well as in critical thinking and problem solving for statistical challenges in data-related researches and applications. The goal is to prepare future leading statisticians in academia, industry, and government.

Type: Ph.D.

Mechanical Engineering

Faculty

J. Yagoobi, George I. Alden Professor and Department Head; Ph.D., University of Illinois at Champaign-Urbana, 1984. Enhancement of heat transfer in macro, micro, and nano-scales, liquid vapor phase change, electrohydrodynamics, impinging jets, drying
M. Bhatia, Assistant Teaching Professor, Ph.D., Arizona State University, 2014. Understanding the effect of 1D, 2D and 3D defects on structure-property relationships in advanced materials such as magnesium and titanium alloys related to the aerospace, automotive and nuclear industries at different length scales
C. A. Brown, Professor, Director Surface Metrology and Sports Engineering Laboratories; Ph.D., University of Vermont, 1983. Surface metrology, axiomatic design, sports engineering, and manufacturing.
L. Cheng, Assistant Professor, Ph.D., University of Pittsburgh, 2019. Physics-informed machine learning, data-driven multiscale and multiphysics modeling, smart/robotic materials development, additive manufacturing.
D. Cote, Assistant Professor; Ph.D., Worcester Polytechnic Institute, 2014. Integrated computational materials engineering (ICME); computational thermodynamics, kinetics, and solidification; solid state additive manufacturing; cold spray processing; powder metallurgy; microstructural analysis and modeling; through-process modeling; women in STEM outreach.
R. Daniello, Assistant Teaching Professor, Ph.D., University

of Massachusetts, Amherst, 2013. Experimental studies of fluid behavior, microfluidics, superhydrophobic surfaces, wetting behavior and topography
C. Demetry, Professor; Ph.D., Massachusetts Institute of Technology, 1993. Pedagogical research and educational development, materials science and engineering education, educational technology, outcomes of K-12 engineering outreach, mentoring of women and girls in science and engineering
A. Ebadi, Assistant Teaching Professor, Ph .D., University of New Hampshire, 2016. experimental and analytical fluid mechanics, thermofluid processes, non-equilibrium turbulent flow structures, computer-aided design and manufacturing.
M. S. Fofana, Associate Professor, Ph.D., University of Waterloo, Waterloo, Canada, 1993. Nonlinear delay dynamical systems, stochastic bifurcations, regenerative chatter, numerically controlled CAD/CAM machining, vehicle ambulance reliability design and technology, systems engineering analysis, reduction of treatment delays in kidney dialysis, medical and public health engineering, emergency and disaster response robots
C. Furlong, Professor and Director, Center for Holographic Studies and Laser micro-mechaTronics; Ph.D., WPI, 1999. MEMS and MOEMS, micro- /nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.
A. Gnanaskandan, Assistant Professor, Ph.D., University of Minnesota, 2015 CFD, Multiscale modeling, Multiphase flows, Cavitation, Biomedical Acoustics, High-performance parallel computing, Algorithm development
S. I. Guceri, Professor, Ph.D., North Carolina State University, 1976. Rapid fabrication, rapid prototyping, layered manufacturing, additive manufacturing, laser manufacturing, bio-fabrication
Z. Hou, Professor; Ph.D., California Institute of Technology, 1990. Vibration and control, structural dynamics, structural health monitoring, smart materials and adaptive structures, stochastic mechanics, solid mechanics, finite elements, earthquake engineering
D. A. Lados, Milton Prince Higgins II Distinguished Professor of Mechanical Engineering; Director, Integrative Materials Design Center (iMdc); Ph.D., Worcester Polytechnic Institute, 2004. Fatigue, fatigue crack growth, thermo-mechanical fatigue, creep, and fracture of metallic and composite materials – evaluation, advanced material/failure characterization, life predictions, computational modeling and ICME, materials/process/component design and optimization for aerospace, automotive, marine, and military applications; advanced manufacturing – additive manufacturing, metal matrix nano–composites, friction stir welding, cold spray technology, powder metallurgy; residual stress; plasticity; fracture mechanics
F. C. Levey, Associate Teaching Professor; Ph.D., University of the Witwatersrand, 2001. Phase diagrams, phase transformations, shape memory, ferro-alloy casting
J. Liang, Professor; Associate Director, Manufacturing and Materials Engineering; Ph.D., Brown University 2004. Nanofabrication through nonlithographic approaches, additive manufacturing, material processing, resource recycling, and material characterization
Y. Liu, Associate Professor; Ph.D., University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, fiber optic sensors, medical robotics, cell mechanics
M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute, 1990. Physical metallurgy, specifically developing new alloys for improved performance. Materials processing, particularly solidification of metals. The application of thermodynamics, kinetics, and the concepts of heat and mass transfer to modeling processes in materials science and engineering. Metal-matrix nanocomposites.
Z. Mao, Associate Professor; Ph.D., University of California San Diego, 2012. Structural dynamics, vibrations, structural health monitoring and damage prognosis, nondestructive evaluation, physics-enhanced data analytics and uncertainty quantification, noncontact sensing, intelligent systems, manufacturing, energy and transportation infrastructures.
B. Mishra, Kenneth G. Merriam Professor; Director, Metal Processing Institute; Director, Manufacturing and Materials Engineering; Ph.D., University of Minnesota, 1986. Physico-chemical processing of materials, corrosion science and engineering, resource recovery & recycling, critical materials extraction, iron and steelmaking, alloy development, thin film coatings and surface engineering
B. Panchapakesan, Professor; Ph.D., University of Maryland, 2001. Nanomanufacturing, light-driven actuators, micro/nano-opto-mechanical systems, nanotube liquid crystals, 2-D nano-materials, and micro and nanotechnology approaches to capture circulating tumor cells
A. Powell, Associate Professor; Ph.D., Massachusetts Institute of Technology, 1997. Clean production of materials particularly those used in clean energy, electrochemistry, extractive metallurgy, multiscale modeling of materials process fundamentals, industrial ecology
P. Radhakrishnan, Associate Teaching Professor; Ph.D., The University of Texas at Austin, 2014. Automated design and manufacturing; entertainment and medical engineering; optimization, machine learning and software development; kinematics, dynamics and design education
P. M. Rao, Associate Professor; Ph.D., Stanford University, 2013. Nanostructured thin film materials, photoelectrochemical materials, printed electronics and sensors.
A. C. Sabuncu, Assistant Teaching Professor; PhD, Old

Dominion University, 2011. Thermo-fluid science and engineering with a focus on micro&nano scale systems. In addition, expertise on dielectric spectroscopy of biological materials.
B. J. Savilonis, Professor; Ph.D., State University of New York at Buffalo, 1976. Thermofluids, biofluids and biomechanics, energy
C. Scarpino, Instructor/Lecturer; MSc. Worcester Polytechnic Institute, 1994. Teaching faculty for engineering experimentation. Geothermal Heat Pumps. Medical devices for hearing research. Computational modeling of heat transfer in thin films
S. S. Shivkumar, Professor; Ph.D., Stevens Institute of Technology 1987. Plastics, materials science and engineering, biomaterials, food engineering
R. D. Sisson, Jr., George F. Fuller Professor; Ph.D., Purdue University, 1975. Materials process modeling and control, manufacturing engineering, corrosion, environmental effects on metals and ceramics
W. Soboyejo, Professor, Provost; Ph.D., Cambridge University, 1988. Biomaterials, use of nanoparticles for detection and treatment of disease, mechanical properties of materials, use of materials science to promote global development.
J. Stabile, Instructor, MSME, University of Arizona; MEEE, University of Colorado. High efficiency small speaker systems for personal audio. This would include magnetic motor design, linear and rotary actuators, high bandwidth structural design, force balanced transducer design, acoustic structural interaction modeling with finite element analysis, and planar acoustic arrays. 3D additive creation of planar electromagnetic actuators
J. M. Sullivan, Jr., Professor, Associate Department Head; D.E., Dartmouth College, 1986. Development of graphics tools and mesh generation, numerical analysis of partial differential equations, medical image visualization and analysis software development
Y. Wang, William Smith Foundation Dean's Professor; Ph.D., University of Windsor, 2008. Battery materials, structure, manufacturing, design, recycling and safety, electrochemistry based technologies, electrolysis, recycling and sustainability, fundamental electrochemistry, commercialization of technologies
S. Wodin-Schwartz, Associate Teaching Professor; Ph.D., University of California at Berkeley, 2013. MEMS sensor design and fabrication, undergraduate engineering education, active learning and experiential education content development and research, product design.
Y. Zheng, Assistant Professor; Ph.D., University of Michigan, 2016. Advanced and biomedical manufacturing, medical device design, tissue mechanics, biomedical machining process and modeling, catheter-based surgical devices, medical simulation, vascular ultrasound imaging, abrasive machining processes for biomedical and ceramic materials.
Y. Zhong, Associate Professor; Ph.D., Penn State University, 2005. Integrated Computational Materials Engineering (ICME), computational thermodynamics, ab initio, molecular dynamics, machine learning, high-throughput simulations, alloys and ceramics

Emeritus

D. Apelian, Professor Emeritus
H. Ault, Associate Professor Emeritus
R. Biederman, Professor Emeritus
J. M. Boyd, Professor Emeritus
A. H. Hoffman, Professor Emeritus
J. A. Mayer, Jr., Professor Emeritus
R. L. Norton, Professor Emeritus
D. Planchard, Instructor Emeritus
R. J. Pryputniewicz, Professor Emeritus

Areas of Study

The graduate curriculum is divided into five distinct areas of study:

- Fluids Engineering
- Dynamics and Controls
- Structures and Materials
- Design and Manufacturing
- Biomechanical Engineering

These areas support the research interests of the mechanical engineering faculty, which are described under Areas of Research. Graduate courses introduce students to fundamentals of mechanical engineering while simultaneously providing the background necessary to become involved with the ongoing research of the mechanical engineering faculty.

Students also receive credit for special topics under ME 593 and ME 693, and independent study under ISP. Faculty members often experiment with new courses under the special topics designation, although no course may be offered more than twice in this manner. Except for certain 4000-level courses permitted in the B.S./ Master's program, no undergraduate courses may be counted toward graduate credit.

Programs of Study

The Mechanical Engineering Program offers the following graduate degree options:

- Master of Science (M.S.)
- Combined B.S./M.S.
- Doctor of Philosophy (Ph.D.)
- Graduate Certificate Program: Mechanical Engineering for Technical Leaders

Admission Requirements

For the M.S. program, applicants should have a B.S. in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.).
The standards are the same for admission into the thesis and non-thesis options of the M.S. program. At the time of application to the master's program, the student must specify his/her option (thesis or non-thesis) of choice.
For the Ph.D., a bachelor's or master's degree in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.) is required.
The Mechanical Engineering Department reserves its financial aid for graduate students in the Ph.D. program or in the thesis option of the M.S. program.

Areas of Research

The faculty of the Mechanical Engineering Department currently pursue research under the following areas:

- Biomechanical Engineering and Healthcare
- Dynamics, Controls and Robotics
- Energy Science and Engineering
- Materials and Manufacturing
- Mechanics and Design
- Nano and Micro Engineering

Please consult the Mechanical Engineering Department website for a current list of the faculty pursuing research under each of these areas.

Mechanical Engineering Laboratories and Centers

The Mechanical Engineering Program provides a multidisciplinary research and education environment. The facilities are housed in Higgins Laboratories and Washburn Shops. For the laboratories and centers of the other programs within the Mechanical Engineering Department (Aerospace Engineering, Manufacturing Engineering, Materials Process Engineering, and Materials Science and Engineering), please see their corresponding sections in this catalog.

Teaching and Project Laboratories

Design Studio and Computer Classroom

The Higgins Design Studio (HL 234) and the Computer Classroom (HL 230) are both part of the Keck Design Center, and are managed by WPI's Information Technology Services Division. The labs are used for lectures and laboratories in a variety of mechanical design and manufacturing courses, and are also available to students for general-purpose computational work on projects and coursework. The 1600 sq. ft. Higgins Design Studio contains twenty one (21) high-end workstations running software for mechanical design including parametric solid modeling (PTC/Creo, Solidworks, NX, Ideas), structural, thermal, fluid and dynamic analysis (ANSYS, Abaqus, Nastran, Patran, Fluent, Comsol) and general purpose applications (Tecplot, sigmaplot, Mathematica, MatLab, Maple). Auxiliary equipment includes two laser printers and 2 E-size color printer/plotter. The 1575 sq. ft. Computer Classroom (HL 230) contains more than forty (40) workstations, A/V equipment including dual high-resolution projection systems, and a high-speed laser printer. Locally installed software includes Solidworks, AutoCAD, Matlab, Maple, Mathcad, TK Solver, Thermal Analysis software and VisualStudio.Net. The workstations in the Design Studio and Computer Classroom have access to all software available on the WPI campus network, and allow for design collaboration and exchange of design models to manufacturing facilities. Courses served: ES 1020, ES 1310, ME 3310, ME 3311, ME 3320, ME 4320 and many out-of- department courses.

Experimentation Laboratory

The Experimentation Laboratory (HL 031) provides the Mechanical Engineering Department with a modern laboratory for the state-of-art Engineering Experimentation ME 3901 course, required for ME students to satisfy their experimentation requirement. The course provides students with valuable hands-on knowledge and directly addresses all ABET experimentation and related requirements. The 1300 sq. ft. laboratory houses 15 workstations containing Labview-based data acquisition hardware and software. Each workstation is configured for two students working in pairs. A host of standard sensors and transducers (thermocouples, thermistors, RTDs, strain gages, pressure transducers, accelerometers, etc.) complement each workstation bench. The laboratory also contains standard test equipment (DVM, soldering equipment, hand tools, calipers, and micrometers) as well as hardware apparatus such as pressure tanks, orifices, heat exchangers, pressurized air, power, and internet, etc. This laboratory is also used for ES 3011 Engineering Controls I, ME 4322 Modeling and Analysis of Mechatronics, a graduate course on Dynamic Signal Analysis, and Major Qualifying Projects (MQPs) related to engineering experimentation.

Major Qualifying Projects (MQP) Laboratory

The MQP Laboratory (HL 045) is a 450 sq. ft. space for students to assemble and work on their MQPs. The laboratory lies between the Engineering Experimentation Laboratory, giving access to state-of-art electronic sensors and measurement equipment, and the Higgins Machine

Shop, providing lathes, drill presses, milling machines and CNC equipment. The MQP laboratory is equipped with air, water, drains, and hand-tools for fabrication work. Individualized storage exists for capstone design works in progress.

Project Laboratories

The other project laboratory spaces in Higgins Laboratories include HL 005, 006, 017, and 019. HL 005 (1600 sq. ft.) is used primarily to conduct of capstone design projects requiring a large work and assembly area. It also provides space to one of WPI's US First Robotics teams and supports the Robotics Resource Center (HL 009), as well as being the home of WPI's CollabLab, which is a student organization that promotes "maker" culture and collaboration at WPI. The SAE Project Lab (HL 006, 300 sq. ft.) houses the SAE Formula Race Car and other SAE projects. HL 017 and 019 (each approximately 100 sq. ft.) provide further space and resources for conducting course projects and MQP projects.

Manufacturing Facilities

3D Print Laboratory

Rapid Prototyping (RP) technologies, including 3D printing, use a computer-driven, additive process to print solid three-dimensional models one layer at a time almost directly from a computer-aided design (CAD) program. The 3D Print Laboratory (HL 232) houses several executive level RP machines managed by Academic & Research Computing (ARC) Center staff available for students, faculty, and staff across campus. The Dimension SST 1200es prints exclusively with ABS plastic, and the Objet 260 Connex is capable of using a variety of resins that can produce up to 14 different material properties within one part, with over 60 material options available. Submissions to the machines are accepted for any on campus projects (MQP, IQP, course project, graduate research, etc.) that have been approved by an advisor or faculty member, for the production of parts that cannot be easily purchased or created using other on campus resources. Instructions for access can be found at https://www.wpi.edu/research/resources/academic-research-computing/3d-printing, and the staff can be contacted at rapidprototyping@wpi.edu

CNC Teaching Laboratory

The CNC teaching laboratory is located in the Washburn Shops Room 107 and covers 3,140 sq. ft. The CNC machine tools housed within this lab are used for a wide range of student projects including MQPs, and also in ME 1800, ME 3820, and other courses. The laboratory is equipped with one Universal Laser Systems VLS60 Laser Cutter, one Makerbot Replicator 2X, 3 Haas MiniMills and 2 Haas SL10s, 3 band saws, two drill presses, a sheet metal shear and bending break as well as assorted hand tools. Attached to each of the MiniMills and SL10s are computer workstations equipped design and programming software. In addition to the computers located at each of the CNC machine tools, the facility has two computer classrooms, one in Washburn 107 and the other in Washburn 105, which can be configured to contain between 8 and 12 computer workstations. These workstations have access to the design software packages supported on campus as well as our training materials and several Computer Aided Manufacturing (CAM) software packages including Esprit, MasterCam, and SurfCam. The facilities are run by an operations manager and lab machinists who are assisted by undergraduate peer learning assistants (PLAs).

Higgins Machine Shop

The 600 sq. ft. machine shop in Higgins Labs is located in HL 004, and contains 2 CNC Machine tools (a Haas Tool Room Mill and a Haas Tool Room Lathe), as well as a surface grinder, 2 DoAll Mills and a DoAll engine lathe as well as a drill press, 2 band saws and assorted hand tools. A machinist manages and supports the machine shop and project activities with the assistance of undergraduate PLAs.

MEMS Fabrication Laboratory

The MEMS Fabrication Laboratory (HL 106) is a Class 100 cleanroom facility with approximately 500 square feet of floor space, including the gowning area. It is equipped with instrumentation to support photolithography, thermal deposition and oxidation, wet chemistry, metrology, and wafer bonding. Metrology capabilities for the devices that are fabricated, such as profilometry, SEM, AFM, and XRD are available through other ME Department laboratories, including the Materials Characterization Laboratory (see Materials Science and Engineering section of this catalog).

Research Laboratories

Automation and Interventional Medicine Laboratory

The Automation and Interventional Medicine Laboratory (AIM Lab) is located at 85 Prescott Street (Gateway Park). The primary focus of projects in the AIM Lab is medical robotics including: robotic surgery, image-guided surgery, MRI-compatible mechatronics, rehabilitation robotics, socially assistive robotics, and biofabrication. The lab contains 10 student workstations, equipment for mechanical and electrical design, construction, configuration, and testing of robots, control systems, and automated test fixtures, including state-of-the-art electronics testing and micro-electronics assembly equipment and supplies. An NDI Polaris optical tracker is available for motion capture. The lab houses MRI robot controllers developed in the AIM lab and custom control electronics for high precision control of piezoelectric motor drive waveforms and corresponding robotic system testbeds. A daVinci Research Kit (dVRK) surgical robot is also available in the lab which includes the Intuitive Surgical robot with custom open control systems. Additional access to a 3T Philips MRI scanner and affiliated personnel is available through collaboration with the nearby UMass Medical School. Collaboration with the Brigham and Women's Hospital provides a second clinical site. BWH has specially configured scanners for real-time image acquisition and scanner control readily implemented with the robot. The Advanced Multimodality Image Guided Operating (AMIGO) suite provides an ideal clinical validation environment. The research in the AIM Lab is directed by Prof. G. Fischer. Further information can be found at http://aimlab.wpi.edu/.

Medical and Manufacturing Innovation Laboratory

The Medical and Manufacturing Innovation Lab (MedMan) is located in HL 029, 037, and 039 on the main campus, as well as the Collaborative Lab of the PracticePoint at the Gateway Park. RESEARCH The MedMan goal is to advance engineering science and technology to enhance healthcare. Specifically, MedMan applies advanced robotics, manufacturing, and design for safety, quality, efficiency, and economy in healthcare service and research. MedMan balances fundamental science and clinical applications, producing research articles and patents, scientists and entrepreneurs. PROJECTS Some representative projects are high-speed grinding inside human arteries to clear the blockage and treat cardiovascular diseases, high-speed machining of blood clot inside the human brain to treat stroke, a tele-ultrasound imaging system with intuitive user interfaces, robotic catheterization for neuro intervention, mechanical testing of blood clot, atherosclerotic plaque, and brain tissues, hydrodynamic polishing for 3D printed internal channels. COLLABORATION MedMan has been extensively collaborating with healthcare organizations and medical schools nationwide including Beth Israel Deaconess Medical Center, Mayo Clinic, VA Ann Arbor Healthcare System, Saint Vincent Hospital, University of Massachusetts Medical School, University of Michigan Medical School, and Massachusetts College of Pharmacy and Health Sciences. MedMan has also worked with medical device companies including Boston Scientific, Cardiovascular Systems Inc., Endovascular Engineering, and Calcium Solutions. The MedMan Lab is directed by Prof. Y. Zheng. Further information can be found at http://medman.wpi.edu/.

Metal Additive Manufacturing Lab

At metal additive manufacturing lab, we advance the state-of-the-art in additive manufacturing by working at the intersection of mechanical engineering, materials science, and manufacturing. We specifically use laser powder bed fusion, electron beam powder bed fusion, and wire arc additive manufacturing processes on structural materials such as titanium, nickel, aluminum-based alloys and steels. Our goal is to develop and utilize process-structure-property relations for different processes and materials to achieve desired microstructures and properties. Our lab has an SLM 125 laser powder bed fusion equipment that is suitable for parameter development using small quantities of powders which is especially advantageous for materials development activities. This machine is also equipped with in-situ monitoring capabilities such as melt pool monitoring and laser power monitoring. We also leverage collaborations with other universities, national labs, and companies for access to equipment and complementary skills to achieve our goals. The research in the metal additive manufacturing lab is directed by Prof. S.P. Narra. Further information can be found at https://sites.google.com/view/narrateam/home.

Multi-Scale Heat Transfer Laboratory

The Multi-Scale Heat Transfer (MHT) Laboratory is located in HL 248, and investigates the enhancement of heat transfer and mass transport in nano-, micro-, and macro-scales, with and without working fluid phase change (liquid/vapor), in the presence and absence of gravity utilizing various mechanisms of electrohydrodynamics (EHD). The MHT Laboratory also studies the augmentation of heat transfer with micro-scale phase change materials under various fluid flow configurations. MHT Laboratory features the following two-phase flow experimental apparatuses: EHD pump in micro scale for water droplet activation; multi-functional in-tube (internal forced convection) condensation and boiling in horizontal configuration using EHD polarization force; external condensation in horizontal configuration using EHD induction pumping; external condensation in vertical configuration using EHD polarization force; in-channel (internal forced convection) condensation in horizontal configuration using EHD induction pumping; two-phase loop with EHD induction pumping; and pool boiling for low and high pressure refrigerants using EHD polarization force. The MHT Laboratory also features several flexible pumps in various configurations and sizes. Supporting equipment include a large scale two-phase system (heat pipe loop), a unique high voltage, three-phase power supply, several high voltage (0-50kV) dc power supplies, a high-speed video system, micro-fiber optic temperature measurement device, high resolution infrared camera , thermistors, heat flux sensors, pressure transducers, flow meters, vacuum pumps, recirculating chillers, oscilloscope, multi-meters, and desktop computers. The research in the MHT Lab is directed by Prof. Prof. J. Yagoobi. Further information can be found at http://mht.wpi.edu/.

NanoEnergy Laboratory

The NanoEnergy Lab is located in Rooms 4916 and 4918, 50 Prescott St. (Gateway Park II), and targets the synthesis and study of nanomaterials for energy conversion applications, particularly for converting solar energy to electrical or chemical energy (photovoltaic and photoelectrochemical energy conversion), and for printed electronics applications, including printing of flexible hybrid electronics and sensors. Materials synthesis equipment in the NanoEnergy Lab includes vapor deposition (flat-flame burner and multi-zone tube furnace), hydrothermal synthesis reactors, solution deposition (fume hood, spincoater), various furnaces for annealing materials, and an advanced R&D inkjet printer and supporting equipment for ink development and characterization including a rheometer, tensiometer/goniometer, particle sizer, and high speed camera. Light sources, integrating spheres, spectrometers, a potentiostat, electrochemical cells and chemical sensors are available for the characterization of optical, electronic, photovoltaic and photoelectrochemical properties and behavior of materials. The research in the NanoEnergy Lab is directed by Prof. P. Rao. Further information can be found at http://nanoenergy.wpi.edu/.

Optomechanics Laboratory

The WPI Optomechanics Lab is located in Rooms 4934 and 4938, 50 Prescott St. (Gateway Park II). The overarching goal is to develop tools based on coupling between optics and mechanics at the micro- and nanoscale, and applying these tools to tackle challenging problems at the intersection of various disciplines. The main research carried out includes fiber optical tweezers, silicon nanomechanics, silicon nanophotonics, optofluidics, and fiber optic sensors. The research in the Optomechanics Lab can find applications in cell mechanics, on-chip disease diagnosis, precision displacement/force measurements, and biomedical sensing. The lab has various facilities for optical and mechanical research at the micro/nanoscale, such as a tunable diode laser, pigtailed laser diodes, automatic fiber fusion splicers, fiber end polisher, and a large variety of photodetectors and power meters. There are various microscopes available for imaging and measurements, including one research-grade inverted fluorescence microscope for biological research and a long-working-distance microscope for nanophotonic and microfluidic research. The lab is specialized in home-made fiber optical tweezer systems, which enable non-contact nanoparticle manipulation and picoNewton force measurements. Piezo stages and a 6-GHz electronic spectrum analyzer enable nanometer displacement control and GHz-range dynamic signal measurements. The research in the Optomechanics Laboratory is directed by Prof. Y. Liu. Further information can be found at http://optomech.wpi.edu/.

Small Systems Laboratory

The Small Systems Laboratory (SSL) is located in HL 124, and is dedicated to the development of multi-functional materials, devices and systems at the macro-, micro-, meso- and nanoscales. Our work spans multiple areas bridging multiple disciplines and multiple length scales. Facilities at SSL include fabrication and characterization units for advanced materials, device processing and testing and biomaterials characterization. Specific ongoing research projects are in the area of novel nanocomposites, energy efficient materials and devices, stimuli responsive materials, photoconductive devices and biomedical nanotechnology. Research in the SSL is directed by Prof. B. Panchapakesan. Further information can be found at https://wp.wpi.edu/baloolab/.

Soft Robotics Laboratory

The Soft Robotics Laboratory is located in HL 127, and supports personnel and equipment required for the design, development, and control of next-generation soft, flexible, and semi-rigid robotic systems. Projects in the lab include studying and developing soft robotic snakes, octopus arms, origami-inspired hexapods, tentacles, flying robots, wearable haptic interfaces, human-robot interaction, and multi-robot systems. Equipment in the Soft Robotics lab includes devices for design, fabrication, experimentation, and analysis, including an Epilog Zing 24 CO2 laser cutter, a dual nozzle 3D printer, a motion capture area, various semi-rigidware packages for mechanical and electronic design, a full custom-made flexible circuit fabrication and assembly equipment suite, a large-workspace optical microscope, an elastomeric fabrication workbench, and various data acquisition and analysis systems. The lab currently supports research activities in elastomeric robotic systems, printed circuit and sensor manufacturing, origami-inspired foldable systems, assistive soft robotic monitoring, bio-inspired stereo vision, and prosthetic robotics. Research in the Soft Robotics Laboratory is directed by Prof. C. Onal. Further information can be found at http://softrobotics.wpi.edu/.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world. The lab is directed by Prof. C. Brown.

Research Centers

Center for Advanced Research in Drying

The Center for Advanced Research in Drying (CARD) is a National Science Foundation (NSF) Industry/University Cooperative Center (I/UCRC) devoted to research in drying of moist, porous materials such as food and other agricultural products, forestry products, chemical products, textiles, and biopharmaceuticals. CARD was founded by WPI as a lead institution, and the University of Illinois at Urbana-Champaign. Examples of the current CARD research areas include:

- Drying Processes/Systems Design and Simulation
- Optimizing Product Quality and Energy Consumption during Drying by Solving Multi-scale Transport Models
- Nano- and Micro-Technology in Drying Applications
- Innovative Concepts in Drying of Moist Porous Materials
- Moisture Management for Food Quality, Stability and Safety
- Phase Behavior of Biopolymers and Impact on Product Quality
- Machine Learning Enabled Smart Drying
- Mechanical Modeling and Computer Software Tracking
- Product Microstructure and Surface Metrology Characterization
- No-Phase-Change Dehydration Schemes and Other Novel Drying Concepts
- Innovative Impinging Jets with and without Chemical Reactions for Drying, Heating, and Cooling Applications
- Energy Auditing
- Development of Unique Sensors

Research in CARD is directed by Prof. J. Yagoobi. Further information and a list of participating faculty members can be found at http://www.dryingresearch.org/.

Center for Holographic Studies and Laser micro-mechaTronics

The laboratories of the Center for Holographic Studies and Laser micro-mechaTronics (CHSLT) cover over 2,800 sq. ft and support activities ranging from fundamental studies of laser light interaction with materials to sophisticated applications in metrology. Research at the CHSLT is externally funded in areas relating to electronic packaging, high density separable electronic interconnections for high speed digital applications, radar technology, microelectronics, micromechanics, submarine technology, jet engine technology, MEMS, nanotechnology and picotechnology, to name a few. The laboratories are furnished with He-Ne lasers, Ar-ion lasers, Nd:YAG lasers, nanosecond high energy pulsed laser, and diode lasers, as well as supporting instrumentation systems. In addition, the Nano-Indentation (NIN) system is being developed for studies of mechanical properties of materials in sub-micron geometries. The CHSLT has its own computational facilities for Finite Element, Finite Difference, and Boundary Element analysis, modeling, and simulation. The metrological applications at the CHSLT concentrate on holographic interferometry, laser speckle metrology, fiber optic sensors, analytical and computational modeling of structural behavior under static as well as dynamic loading conditions, and other areas of current interest. In the area of holographic interferometry, the CHSLT maintains holographic systems for studies of static as well as dynamic problems. These systems range from conventional double-exposure holography, to real-time and time-average holography, heterodyne holography, stroboscopic heterodyne holography, pulsed laser holography, and electro-optic holography (EOH). The EOH system allows for direct electronic acquisition and processing of interferometric data in real-time and sets a new standard for quantitative holographic analysis. The CHSLT also conducts experimental and computational research in the field of nanoindentation studies in conjunction with a laboratory system which is uniquely suited to measure elastic, plastic, creep, and fracture properties of materials in submicron geometries. In addition, the CHSLT is equipped with a complete laser vibrometer system, GHz frequency range storage oscilloscopes, a spectrum analyzer, a self-contained network of personal computers, UNIX based workstations and image processors, a host of supporting instrumentation, and a library of finite element analysis and general purpose software. A well-equipped electrical engineering and instrument development laboratory, a fiber optic preparation laboratory, an optical microscopy laboratory and a multifunctional dark room are also parts of the CHSLT. The strengths of the CHSLT lie in a comprehensive utilization of laser technology, optics, computational methods, mechanical engineering, materials science and engineering, and computer data acquisition and processing. Research in CHSLT is directed by Prof. C. Furlong. Further information can be found at http://chslt.wpi.edu/.

B.S./M.S. in Mechanical Engineering

The Mechanical Engineering Department offers a B.S./Master's program for currently enrolled WPI undergraduates. Students in the B.S./Master's program may choose either the thesis or non-thesis M.S. option. The department's rules for these programs vary somewhat from the Institute's rules. Students in the B.S./Master's program are permitted to count units/credits towards both their B.S. and Master's degrees. For the purposes of this double-counting, 1/6 WPI undergraduate unit is equivalent to 1 graduate credit. For regular courses, this means that term-long 4000-level courses (1/3 undergraduate unit) are worth 2 graduate credits, term-long graduate courses (2 graduate credits) are worth 1/3 undergraduate unit, and semester-long graduate courses (3 graduate credits) are worth 1/2 undergraduate unit. A maximum of 2 undergraduate units (twelve graduate credits) may be counted toward both the undergraduate and graduate degrees. Of these, at most 1 undergraduate unit (six graduate credits) can be from 4000-level undergraduate courses, and none may be from courses lower than the 4000-level. No extra work is required in the 4000-level courses. The remainder of the double-counted credits must come from graduate courses. Courses that can be double-counted include independent study, directed research and special topics courses. A grade of B or better is required for any course to be counted toward both degrees.
Students can apply to the BS/MS program by submitting an MS application to WPI Graduate Admissions and selecting the BS/MS option.

The application for the B.S./Master's program must include a list of courses that the applicant proposes to count toward both his/her undergraduate and graduate degrees. In most cases, the list consists of courses that the applicant will take in the senior year.

Applications will not be considered if they are submitted prior to the second half of the applicant's junior year. Ideally, applications (including recommendations) should be completed by the early part of the last term (usually D-term) of the junior year.

Students in the B.S./Master's program who choose the thesis M.S. option are encouraged to pick a thesis area of research that is closely related to the subject of their major qualifying project. Those students in the B.S./Master's program who complete their B.S. degrees in May and choose the thesis option are encouraged to begin their thesis research during the summer immediately following graduation.

A detailed written description of the B.S./Master's program in mechanical engineering can be obtained from the mechanical engineering graduate secretary.

Type: B.S./M.S.

Graduate Certificate Program: Mechanical Engineering for Technical Leaders (METL)

Companies recognize that employees who pursue graduate education oftentimes become the future technical leaders within their organization. As leaders, it is important that they possess not only the engineering skills to understand technical problems that require novel and innovative solutions, but also the business and managerial skills to harness the resources (human and capital) to implement these solutions. This certificate combines graduate mechanical engineering coursework to enhance their technical expertise along with leadership and management coursework to empower them to lead technical teams, make sound business decisions and bring their projects to successful conclusion.

Requirements:

9 credits in graduate level Mechanical Engineering courses*
9 credits in graduate level Business courses**
* Note: Students may petition the Mechanical Engineering Graduate Committee to count up to 4 credits in MTE graduate courses. Petitions must be approved before students register for these MTE credits.
**Note: Students may use CE 580 (Advanced Project Management) toward this requirement.

Admission to the Certificate Program:

Students wishing to enroll in the METL Certificate program must submit a full M.S. graduate application.

Successful Completion of the METL Certificate Program:

Successful completion of the METL certificate program requires:

- completion of the 18 credits distributed as described above; and

- an overall GPA of at least 3.0.

Subsequent Admission into the M.S. program in Mechanical Engineering:

Students wishing to continue their studies in the M.S. program in Mechanical Engineering will be admitted upon request provided that they have:

- completed the METL certificate program; and
- earned a GPA of at least 3.0 within the 9 credits of M.E. courses (including any AE and MTE credits permitted by petition).

For B.S. students who continue on to the M.S. program in Mechanical Engineering, any MTE credits that have been used to satisfy the METL certificate requirements will be counted as M.E. credits toward the M.S. degree. Current graduate students in the ME program are also allowed to obtain this METL certificate. All students who wish to apply to the METL certificate program should submit a formal application to WPI Graduate Admissions.

Type: Certificate

M.S. in Mechanical Engineering

When applying to the master of science program, students must specify their intention to pursue either the thesis or non-thesis M.S. option. Both the thesis and non-thesis options require the completion of 30 graduate credit hours. Students in the thesis option must complete 12 credits of thesis research (ME 599), whereas students in the non-thesis option may complete up to 9 credits of directed research (ME 598). The result of the research credits (ME 599) in the thesis option must be a completed master's thesis. The number of directed research credits (ME 598) completed in the non-thesis option can range from 0 to 9. In the thesis option, the distribution of credits is as follows:

- ME 5000 (2 graduate credits) OR 3 graduate credits in mathematics (e.g. MA 501). ME 5001 does not satisfy this requirement.
- 10 graduate credits in mechanical engineering if 2-credit ME 5000 is selected above OR 9 graduate credits in mechanical engineering if 3 graduate credits in mathematics is selected above. These credits do not include ME 5000. MTE, MFE and MPE courses are not considered credits in mechanical engineering
- 12 credits of thesis research (ME 599)
- 6 graduate credits of electives within or outside of mechanical engineering

In the non-thesis option, the distribution of credits is as follows:

- ME 5000 (2 graduate credits) OR 3 graduate credits in mathematics (e.g. MA 501). ME 5001 does not satisfy this requirement.
- 19 graduate credits in mechanical engineering if 2-credit ME 5000 is selected above OR 18 graduate credits in mechanical engineering if 3 graduate credits in mathematics is selected above. These credits do not include ME 5000. These credits can include up to a maximum of 9 credits of directed research (ME 598). MTE, MFE and MPE courses are not considered credits in mechanical engineering.
- 9 graduate credits of electives within or outside of mechanical engineering

In either option, all full-time students are required to register for the graduate seminar (ME591) every semester.

Academic Advising

Upon admission to the M.S. program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan must be made before the first registration. Prior to registering for additional credits, the student must specify an academic advisor with whom the remaining course of study is arranged. The plan must be approved by the mechanical engineering graduate committee.

For students in the thesis option, the academic advisor is the thesis advisor. Prior to completing more than 18 credits, every student in the thesis option must form a thesis committee that consists of the thesis advisor and at least two other mechanical engineering faculty members from WPI with knowledge of the thesis topic.

The schedule of academic advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan the first 9 credits of study.
- Academic advisor—selected by student prior to registering for more than 9 credits. For thesis option students, the academic advisor is the thesis advisor.
- Plan of Study—arranged with academic advisor prior to registering for more than 9 credits.
- Thesis committee (thesis option only) —formed prior to registering for more than 18 credits. Consists of the thesis advisor and at least two other mechanical engineering faculty members from WPI.

This schedule ensures that students are well advised throughout the program, and that students in the thesis option are actively engaged in their research at the early stages of their programs.

Thesis Defense

Each student in the thesis option must defend his/her research during an oral defense, which is administered by an examining committee that consists of the thesis committee and a representative of the mechanical engineering graduate committee who is not on the thesis committee. The defense is open to public participation and consists of a 30-minute presentation by the student followed by a 30-minute open discussion. At least one week prior to the defense each member of the examining committee must receive a copy of the thesis. One additional copy must be made available for members of the WPI community wishing to read the thesis prior to the defense. Public notification of the defense must be given by the mechanical engineering graduate secretary. The examining committee will determine the acceptability of the student's thesis and oral performance. The thesis advisor will determine the student's grade.

Changing M.S. Options

Students in the non-thesis M.S. option may switch into the thesis option at any time by notifying the mechanical engineering graduate committee of the change, provided that they have identified a thesis advisor, formed a thesis committee, and have worked out a Plan of Study with their thesis advisor. Subject to the thesis advisor's approval, directed research credits (ME 598) earned in the non-thesis option may be transferred to thesis research credits (ME 599) in the thesis option.

Any student in the thesis option M.S. program may request a switch into the non-thesis option by submitting the request in writing to the mechanical engineering graduate committee. Before acting on such a request, the graduate committee will require and seriously consider written input from the student's thesis advisor. Departmental financial aid given to the thesis-option students who are permitted to switch to the non-thesis option will automatically be withdrawn. Subject to the approval of the mechanical engineering graduate committee, a maximum of 9 credits of thesis research (ME 599) earned by a student in the thesis option may be transferred to directed research credit (ME 598) in the non-thesis option.

Type: Master of Science

Ph.D. in Mechanical Engineering

The course of study leading to the Ph.D. degree in mechanical engineering requires the completion of 90 graduate-level credits beyond the bachelor's degree, or 60 graduate-level credits beyond the master's degree. For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

Coursework:

Courses in M.E (incl. Special Topics and ISP)	15 credits
Courses in or outside of M.E	15 credits
Dissertation Research (ME 699)	30 credits
Other:	
Additional coursework	
Additional Dissertation	
Research (ME 699)	30 credits
Supplemental Research	(ME 598, ME 698)
TOTAL	90 credits

For students proceeding from master's to Ph.D. degree, the 60 credits should be distributed as follows:

Coursework: (incl. Special Topics and ISP)	12 credits
Dissertation Research (ME 699)	30 credits
Other:	
Additional coursework	
Additional Dissertation	
Research (ME 699)	18 credits
Supplemental Research (ME 598, ME 698)	
TOTAL	60 credits

In either case, the result of the dissertation research must be a completed doctoral dissertation. Only after admission to candidacy may a student receive credit toward dissertation research under ME 699. Prior to admission to candidacy, a student may receive up to 18 credits of predissertation research under ME 698. All full-time students are required to register for the graduate seminar (ME 591)every semester.

Academic Advising

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan should be arranged before the first day of registration.

Prior to registering for any additional credits, the student must identify a permanent dissertation advisor who assumes the role of academic advisor and with whom a suitable dissertation topic and the remaining Plan of Study are arranged. Prior to completing 18 credits, the student must form a dissertation committee that consists of the dissertation advisor, at least two other mechanical engineering faculty members, and at least one member from outside the department. These committee members should be selected because of their abilities to assist in the student's dissertation research.

The schedule of advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan first 9 credits of study.
- Dissertation advisor—selected by student prior to registering for more than 9 credits.
- Program of study—arranged with Dissertation advisor prior to registering for more than 9 credits.
- Dissertation committee—formed by student prior to registering for more than 18 credits. Consists of dissertation advisor, at least two M.E. faculty, and at least one outside member.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Admission to Candidacy

Admission to candidacy will be granted when the student has satisfactorily passed a written exam intended to measure fundamental ability in three of the following nine areas: fluid mechanics, heat transfer, dynamics, controls, structures, materials, design, manufacturing, and biomechanical engineering. The three areas are selected by the student, with the approval of the PhD advisor. The exam questions will be at the first-year graduate level. The Ph.D. candidacy exam is given in September and January. For students who enter the program with a master's degree in mechanical engineering, the exam must be taken for the first time after one semester of study (i.e.: in January if they began in the fall; and in September if they began in the spring.). For all other students, the exam must be taken for the first time after two semesters of study (i.e. in September if they began in the fall, and in January if they began in the spring.) Any student who does not pass the exam in all three areas chosen must retake the exam (in the areas not passed) one semester later (i.e.: in September if they did not pass in January; and in January if they did not pass in September). Students are not allowed to take the exam more than twice. The details of the examination procedure can be obtained from the mechanical engineering graduate committee.

Dissertation Proposal

Each student must prepare a written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. An important part of the written and oral proposal should be a description of the potential applications and societal impact of the research. In particular, the written proposal should include a chapter to define the topic of the PhD research, a chapter to review the state of the art, a chapter to summarize the proposed research plan and the preliminary data obtained to date, and any other chapters necessary to describe the proposed PhD research. The written proposal should be submitted to the committee 7 days before the oral presentation.The proposal must be made within 18 months of admission to candidacy. Both the written and oral proposals are presented to the dissertation committee and a representative from the mechanical engineering graduate committee. The prepared portion of the oral presentation should not exceed 30 minutes, and up to 90 minutes should be allowed for discussion. If the dissertation committee and the graduate committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, then the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 45 minutes allowed for discussion. Students can continue their research only if the proposal is approved.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the dissertation committee and a representative of the mechanical engineering graduate committee who is not on the dissertation committee. In addition to providing a summary of the relevant literature and a description of the techniques employed, technical issues addressed, and results obtained, both the dissertation and the oral defense should include a description of the potential applications and societal impact of the research. The defense is open to public participation and consists of a 45-minute presentation followed by a 45-minute open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the mechanical engineering graduate secretary. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Type: Ph.D.

Neuroscience

Affiliated Faculty

J. Srinivasan, Associate Professor, Biology and Biotechnology and Program Director, Neuroscience; Ph.D., University of Tuebingen, Germany; neural networks underlying social behaviors, role of olfactory dysfunction in neurodegenerative disorders, optogenetics & engineering of neural networks.
D. R. Albrecht, Associate Professor, Biomedical Engineering; Ph.D., University of California, San Diego; bioMEMS, microfluidics, quantitative systems analysis and modeling, biodynamics, neural circuits and behavior, optogenetics, high-throughput chemical/genetic screens, tissue engineering, 3-D cell micropatterning, dielectrophoresis.
A. Arnold, Assistant Professor, Mathematical Sciences; Ph.D., Case Western University, 2014. Mathematical biology, bayesian inference, parameter estimation in biological systems.
S. Barton, Associate Professor, Humanities and Arts; Ph.D. University of Virginia, 2012. Human- robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.
F. Bianchi, Professor, Humanities & Arts;
K. L. Billiar, Professor and Department Head, Biomedical Engineering; Ph.D., University of Pennsylvania; Biomechanics of soft tissues and biomaterials, mechanobiology, wound healing, tissue growth and development; functional tissue engineering, regenerative medicine.
S. C. Burdette, Associate Professor, Chemistry and Biochemistry; Ph.D., Massachusetts Institute of Technology; synthesis of fluorescent sensors for iron, photoactive chelators for delivery of metal ions in cells, applications of azobenzene derivatives with unusual optical properties, polymers to detect metal contaminants in the environment.
L. Capogna, Professor and Department Head, Mathematical Sciences; Ph.D., Purdue University, 1996. Partial differential equations.
R. E. Dempski, Associate Professor, Chemistry and Biochemistry; Ph.D., Massachusetts Institute of Technology; molecular mechanism of human zinc transporter, structure-function of light activated channel, optogenetics.
J. Doyle, Associate Professor, Social Science and Policy Studies; Ph.D., University of Colorado-Boulder, 1991. Mental models of complex systems, environmental cognition and behavior.
J. B. Duffy, Associate Professor and Department Head, Biology and Biotechnology; Ph.D., University of Texas; defining signaling pathways that program cellular diversity.
M. Elmes, Professor, Robert A. Foisie School of Business; Ph.D., Syracuse University, 1998. Interpersonal and group dynamics in complex organizations, leading change, leadership ethics.
R. Falco, Assistant Teaching Professor, Humanities & Arts;
N. Farny, Assistant Professor, Biology and Biotechnology; Ph.D., Harvard University, 2009. Translational control of gene expression and cellular stress response in neurodegenerative disease and autism spectrum disorder.
A. Gericke, Professor and Department Head, Chemistry and Biochemistry; Dr.rer.nat., University of Hamburg; biophysical characterization of lipid-mediated protein function, development of vibrational spectroscopic tools to characterize biological tissue.
L. Harrison, Assistant Professor, Computer Science; Ph.D., UNC-Charlotte, 2013. Information visualization, visual analytics, human-computer interaction.
M. Humi, Professor, Mathematical Sciences; Ph.D., Weizmann Institute of Science, 1969. Mathematical physics, applied mathematics and modeling, Lie groups, differential equations, numerical analysis, turbulence and chaos.
S. Ji, Associate Professor, Biomedical Engineering; D.Sc., Washington University in St. Louis; Biomechanics, brain injury, finite element analysis, multi-scale modeling, neuroimaging, medical image analysis, sports medicine.
J. A. King, Professor, Biology and Biotechnology and Peterson Family Dean of Arts and Sciences; Ph.D., New York University; M.S, City University of New York; neuronal plasticity associated with neurological and psychiatric disorders utilizing functional magnetic resonance imaging, molecular biology and behavior.
X. Kong, Associate Professor, Computer Science; Ph.D., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.
D. Korkin, Professor, Computer Science; Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology, data mining, machine learning.
K. Lee, Assistant Professor, Biomedical Engineering; Ph.D., Massachusetts Institute of Technology; mechanobiology, cell mechanics, cell morphodynamics, cancer cell migration, quantitative live cell imaging, quantitative cell biology, computational image analysis, data mining, genome engineering, optogenetics.
Y. Mendelson, Professor, Biomedical Engineering; Ph.D., Case Western Reserve University; Biomedical sensors for invasive and noninvasive physiological monitoring, pulse oximeters, microcomputer-based medical instrumentation, signal processing, wearable wireless biomedical sensors, application of optics to biomedicine, telemedicine.
R. Neamtu, Associate Teaching Professor, Computer Science; Ph.D., Worcester Polytechnic Institute;
S. Olson, Associate Professor, Mathematical Sciences; Ph.D., North Carolina State University 2008. Mathematical

biology, computational biofluids, scientific computing.
M. B. Popovic, Assistant Research Professor, Physics; Ph.D., Boston University. Human neurosensory-motor organization, soft robotics, wearable robotics, assistive robotics, human augmentation systems.
A. Rodriguez, Assistant Professor, Social Science & Policy Studies; Ph.D., University of California, Los Angeles;
C. Ruiz, Professor, Computer Science; Ph.D., Maryland, 1996. Data mining, knowledge discovery in databases, machine learning.
E. F. Ryder, Associate Professor, Biology and Biotechnology; Ph.D., Harvard University; M.S., Harvard School of Public Health; bioinformatics and computational approaches to understanding biological systems.
S. F. Scarlata, Professor, Chemistry and Biochemistry; Ph.D., University Illinois Urbana-Champaign; Mechanisms of cell signaling using fluorescence imaging and correlation methods, how mechanical deformation affects calcium fluxes in cells.
J. L. Skorinko, Professor, Social Science & Policy Studies; Ph.D., University of Virginia; soc ial environmental cues, stigmas and stereotyping, perceptions of others
E. T. Solovey, Assistant Professor, Computer Science; Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.
I. Stroe, Associate Teaching Professor, Physics; Ph.D., Clark University. Experimental biophysics, protein structure, dynamic, and functionality.
D. Tang, Professor, Mathematical Sciences; Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.
L. V. Titova, Associate Professor, Physics; Ph.D., University of Notre Dame. THz spectroscopy of nanomaterials for energy applications; optical excitations and ultrafast carrier dynamics in nanomaterials.
L. Vidali, Associate Professor, Biology and Biotechnology; Ph.D., University of Massachusetts-Amherst; understanding the molecular and cellular mechanisms underlying the role of the cytoskeleton in plant cell organization and growth.
C. E. Wills, Professor and Department Head, Computer Science; Ph.D., Purdue, 1988. Distributed systems, networking, user interfaces.
M. Wu, Visiting Assistant Professor, Mathematical Sciences; Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.
Z. Wu, Associate Professor, Mathematical Sciences; Ph.D., Yale University, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.
V. Yakovlev, Research Associate, Mathematical Sciences; Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences, 1991. Antennas for MW and MMW communications, electromagnetic fields in transmission lines and along media interfaces, control and optimization of electromagnetic and temperature fields in microwave thermal processing, issues in modeling of microwave heating, computational electromagnetics with neural networks, numerical methods, algorithms and CAD tools for RF, MW and MMW components and subsystems.
H. Zhang, Assistant Professor, Biomedical Engineering; Ph.D., Johns Hopkins University; Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Program of Study

The Neuroscience program offers graduate studies toward the M.S. degree. This program is designed to provide students with a strong foundation in molecular, psychological, computational, quantitative and interdisciplinary approaches to neuroscience. Neuroscience is a critical and challenging area of human endeavor. Our faculty and students thrive from the synergy of our diverse approaches to understanding the brain and nervous system. The faculty involved in the program have a strong record of extramural funding and provide an excellent research-oriented environment. As a 'Program' in Neuroscience, faculty from departments across campus train our students and collaborate on research and projects. The program comprises four broadly defined areas:

- Cellular and Molecular Neuroscience: Training in neurophysiological methods such as electrophysiology, optogenetics, molecular biology, genetics, biochemistry and biophysics, appropriate to topics in neurobiology.
- Systems Neuroscience: Training in structure-function relationship of neural networks, neural substrates of learning and memory, psychopharmacology of nervous system disorders including Alzheimer's disease.
- Computational Neuroscience: Training in the use of experimental and theoretical methods for the analysis of brain function.
- Psychological Science: Training in how the brain and nervous system interact with development, mental health, cognition, social processes, and behavior.

Master of Science in Neuroscience

Goals:

1. Prepare future professional students and industry leaders in the field of neuroscience so that they are ready to help solve the world's most challenging problems affecting the brain.
2. Create a comprehensive educational interdisciplinary program in neuroscience at WPI that distinguishes our program from others typically offered at the master's level due to the focus on both basic and translational neuroscience coupled with a strong computational base and links to industry partners.
3. Development of research areas linking neuroscience to areas like data science and biomedical engineering, in order to train students in a multidisciplinary approach.

Admissions Requirements

Students applying to the M.S. Degree program in Neuroscience are expected to have a bachelor's degree in biology, biochemistry, computer science, mathematics, psychology, neuroscience, or a related field, and to have taken introductory courses in a neuroscience-related field such as biology, biochemistry, computer science, mathematics and/or psychology. For example, a student with a bachelor's degree in biology is expected to have also completed courses in calculus and statistics prior to submitting an application. A strong applicant who is missing background coursework as needed for course requirements may be admitted, with the expectation that he or she will take and pass one or more undergraduate courses in this area of deficiency either during the summer prior to admission or within the first semester after admission. These remedial courses will not count towards meeting the M.S. degree requirements. The determination of what course or courses will satisfy this provision will be made by the Neuroscience Faculty Steering Committee, which consists of faculty members from the participating departments at WPI. Students who are not WPI undergraduates or graduates will be required to submit GRE/TOEFL scores.

B.S./M.S. in Neuroscience Program Description

Students enrolled in the B.S./M.S. program must satisfy all the program requirements of their respective B.S. degree and all the program requirements of the M.S. degree in Neuroscience. WPI allows B.S./M.S. students to double-count courses towards both their undergraduate and graduate degrees whose credit hours total no more than 40 percent of the 31 graduate credit hours required for the M.S. degree in Neuroscience (i.e., up to 12 graduate credits or equivalently 2 undergraduate units), and that meet all other requirements for each degree. These courses can include graduate courses as well as certain undergraduate 4000-level courses, listed below, that are acceptable for satisfying Neuroscience M.S. requirements.

In consultation with the student's major Academic Advisor and the Neuroscience Program Director, the student prepares a Plan of Study outlining the selections made to satisfy the B.S./M.S. degree requirements, including the courses that will be double-counted. This Plan of Study must then be approved by the Neuroscience Faculty Steering Committee.

Admissions Requirements

Any WPI undergraduate student may apply to the B.S./M.S. program in Neuroscience. Students are expected to apply for admission to the B.S./M.S. program during their junior year so that they have sufficient time to plan their course selection with their major Academic Advisor and the Neuroscience Program Director.

4000-level courses and projects that can be double-counted

For the 4000-level courses listed below, two graduate credits will be earned towards the B.S./M.S. degree if the student achieves a grade of B or higher.

- Bioinformatics and Computational Biology courses:
  - BCB 4001/BB4801. Bioinformatics
  - BCB 4002/CS 4802. Biovisualization
  - BCB 4003/CS 4803. Biological and Biomedical Database Mining
  - BCB 4004/MA 4603. Statistical Methods in Genetics and Bioinformatics
- Biology and Biotechnology courses:
  - BB/CH 4190. Regulation of Gene Expression
  - BB 4260. Synthetic Biology
  - BB/CH 4170. Experimental Genetic Engineering
- Biomedical Engineering courses:
  - BME/ECE 4011. Biomedical Signal Analysis
  - BME 4201. Biomedical Imaging
- Chemistry and Biochemistry courses:
  - CH 4110. Protein Structure and Function
  - CH 4120. Lipids and Biomembrane Functions
  - CH4160. Membrane Biophysics
  - CH/BBT 4170. Experimental Genetic Engineering
- Computer Science courses:
  - CS 4341. Introduction to Artificial Intelligence
  - CS 4342. Machine Learning
  - CS 4432. Database Systems II
  - CS 4445. Data Mining and Knowledge Discovery in Databases
  - CS 4518. Mobile and Ubiquitous Computing
  - CS 4802/BCB 4002. Biovisualization

- CS 4803/BCB 4003. Biological and Biomedical Database Mining
- Data Science courses:
  - DS 4635/MA 4635. Data Analytics and Statistical Learning
- Mathematics courses:
  - MA 4631. Probability and Mathematical Statistics I
  - MA 4632. Probability and Mathematical Statistics II
  - MA 4635/DS 4635. Data Analytics and Statistical Learning
- Psychology courses:
  - PSY 4800. Special Topics in Psychological Science
  - PSY 4900. Advanced Research in Psychological Science

- Major Qualifying Project (MQP): Up to 3 graduate credits (equal to 1/2 undergraduate unit) can be earned towards fulfillment of the Neuroscience thesis requirement by double counting a Major Qualifying Project, provided that:
  - (1) the MQP involves substantial use of Neuroscience at an advanced level,
  - (2) the thesis research is a continuation or extension of the MQP work,
  - (3) the student satisfies the thesis requirement by completing at least 6 additional credits of NEU 599 Thesis Research, and
  - (4) the M.S. thesis advisor and the Neuroscience Faculty Steering Committee approve the double-counting.
- MQP work may not be double-counted toward the non-thesis option.

Other 4000-level courses and independent studies not on this list but that could be used to satisfy Neuroscience M.S. requirements may be petitioned to double-count. Such petitions need to be approved by the Neuroscience Faculty Steering Committee.

Graduate courses that can be double-counted

A student in the B.S./M.S. Program in Neuroscience can double-count any of the graduate courses listed as electives in the Neuroscience M.S. Degree description in the WPI Graduate Catalog if the course also satisfies a requirement of the student's B.S. degree.

Restricted Undergraduate and Graduate Course Pairs

Some undergraduate and graduate courses have significant overlap in their content. The following table lists these courses. A student can receive credit towards their M.S. degree for at most one of the two courses in any row of this table.

Courses in Bioinformatics and Computational Biology

Undergraduate Course	Graduate Course
BCB 4001/BB 4801 Bioinformatics	BCB 501/BB 581 Bioinformatics
BCB 4002/CS 4802 Biovisualization	BCB 502/CS 582 Biovisualization
BCB 4004/MA 4603 Statistical Methods in Genetics and Bioinformatics	BCB 504/MA 584 Statistical Methods in Genetics and Bioinformatics

Courses in Computer Science

Undergraduate Course	Graduate Course
CS 4341 Introduction to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4342 Machine Learning	CS 539 Machine Learning
CS 4432 Database Systems II	CS 542 Database Management Systems
CS 4518 Mobile and Ubiquitous Computing	CS 528 Mobile and Ubiquitous Computing

Courses in Mathematics

Undergraduate Course	Graduate Course
MA 4631 Probability and Mathematical Statistics I	MA 540 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II	MA 541 Probability and Mathematical Statistics II
DS 4635/MA 4635 Data Analytics and Statistical Learning	MA 543/DS 502 Statistical Methods for Data Science

Type: B.S./M.S.

M.S. in Neuroscience

Students pursuing the M.S. degree in Neuroscience must complete a minimum of 31 credits of relevant work at the graduate level. The M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, and students who plan to pursue a PhD degree later.

Matriculated students will be assigned an academic advisor from the neuroscience program. In consultation with the academic advisor, the student will prepare a Plan of Study outlining the selections that will satisfy the M.S. degree requirements. This Plan of Study must then be approved by the Program's Review Committee, which consists of faculty members from each of the participating departments.

Core Neuroscience Coursework Requirements (Minimum of 19 Credits)

A student in the M.S. program must take courses to satisfy each of the following requirements:
Requirements Minimum Credits

1. At least three Neuroscience courses (Note 1) 9
2. At least one Biology courses (Note 2) 3
3. At least one Computer Science course (Note 2) 3
4. One Bioethics course (Note 3) 1
5. One Scientific Writing or Experimental Design course (Note 4) 3

NOTES

1. Chosen from the list of graduate NEU courses.
2. Chosen from the corresponding lists of Program Elective Courses below
3. For example, BB 551 Research Integrity in the Sciences or ID 500 Responsible Conduct of Research
4. For example, BB 553 Experimental Design and Statistics in the Life Sciences, MA 546 Design and Analysis of Experiments. Courses such as ID 527

Fundamentals of Scientific Teaching and Pedagogy are currently offered for no credit and will be considered for meeting this requirement at which time they are offered to students for credit.

In addition to the 19 credits in the Core Neuroscience Coursework Requirement, M.S. students must complete either the Thesis Option or the Non-thesis Option described below. Students supported with a Teaching Assistantship, Research Assistantship or Fellowship for more than one academic year are required to do the Thesis Option.

M.S. Thesis Option

Students in the M.S. thesis option must complete a 9-credit thesis. Students interested in research, and in particular those who are considering pursuing a Ph.D. degree in Neuroscience or a related area, are strongly encouraged to select the M.S. thesis option. The thesis must be advised or co-advised by a faculty member affiliated with the Neuroscience Program. If the advisor is not a tenure-track faculty at WPI, then a Neuroscience affiliated tenure-track faculty must serve as the thesis co-advisor. A thesis proposal must be submitted to and approved by the student's advisor(s) and the Neuroscience Faculty Steering Committee before the student can register for more than three thesis credits. Upon approval of the thesis proposal, the Steering Committee will appoint a thesis reader, who should be a faculty member affiliated with the Neuroscience program from a department different to that (those) of the thesis advisor(s). The thesis reader will serve as an examiner for the student's thesis. The student then must satisfactorily complete a written thesis that is approved by the thesis advisor(s) and the thesis reader, and present the thesis results to the Neuroscience faculty in a public presentation.

Non-Thesis Option

Students in the M.S. non-thesis option must complete the remainder of the 31 credits required for the M.S. degree using one or both of the following choices:

- A 3-6 credit research or practice-oriented internship. All non-thesis students are strongly encouraged to pursue this choice. The internship is to be carried out in cooperation with a sponsoring organization or affiliated research lab, and must be approved and overseen by a faculty member affiliated with the Neuroscience Program. The faculty member is responsible for supervising the internship and ensuring that the internship has sufficient rigor and content for graduate-level neuroscience work. Internships will often focus on applied projects in an industry setting, although internships could also be completed in a research lab. Students will produce a written report at the conclusion of the internship. The format for the report—which is significantly shorter and less formal than a thesis—will be determined by the student's advisor. Students will also be encouraged to present their work to the Neuroscience faculty in a public presentation.
- Additional Program Elective Courses. Elective courses must include one Neuroscience course (in addition to the three Neuroscience courses in the Core Neuroscience Requirements) and any additional graduate courses on the list of Program Elective Courses below.

Program Elective Courses

Students in the Neuroscience M.S. program may take program electives, as needed, to satisfy the remainder of the 31-credit degree requirement, and to tailor their Neuroscience degree program to areas of personal interest. An elective can be any graduate course listed below, although students are expected to select electives to produce a consistent program of study. Other graduate courses, graduate research credits, or ISGs not on this list may be used with prior approval of the Faculty Steering Committee, and if consistent with the student's Plan of Study.

List of Elective Courses:

Relevant Neuroscience courses:

NEU 501 Neuroscience
NEU 502 Neural Plasticity
NEU 503 Computational Neuroscience
NEU 504 Advanced Psychophysiology
NEU 505 Brain-Computer Interaction

Relevant Bioinformatics and Computational Biology courses:

BCB 501/BBT 581 Bioinformatics
BCB 502/CS 582 Bio visualization
BCB 503/CS 583 Biological and Biomedical Database Mining
BCB 504/MA 584 Statistical Methods in Genetics and Bioinformatics
BCB 510 Bioinformatics and Computational Biology Seminar

Relevant Biology and Biotechnology courses:

BBT 561 Model Systems: Experimental Approaches and Applications
BBT 581/ BCB 501 Bioinformatics
BB570/CH 555 Cell Signaling

Relevant Biomedical Engineering courses:

BME 550 Tissue Engineering
BME 555 BioMEMS and Tissue Micro engineering
BME 560 Physiology for Engineers
BME 583 Biomedical Microscopy and Quantitative Imaging

Relevant Chemistry and Biochemistry courses:

CH 538 Medicinal Chemistry
CH 541 Membrane Biophysics
CH 555D Drug and Regulations
CH 555R Drug Safety and Regulatory Compliance
CH 555/PH597 Cell Mechanics
CH 555/BB570 Cell Signaling

Relevant Computer Science courses:

CS 5007 Introduction to Applications of Computer Science with Data Structures and Algorithms
CS 5084 Introduction to Algorithms: Design and Analysis 84
CS 528 Mobile and Ubiquitous Computing
CS 534 Artificial Intelligence
CS 539 Machine Learning
CS 541/DS 541 Deep Learning
CS 542 Database Management Systems
CS 546 Human-Computer Interaction
CS 548 Knowledge Discovery and Data Mining
CS/RBE 549 Computer Vision
CS/SEME 565 User Modeling
CS/SEME 566 Graphical Models for Reasoning under Uncertainty
CS/SEME 567 Empirical Methods for Human-Centered Computing
CS 573 Data Visualization
CS 584 Algorithms: Design and Analysis
CS 585/DS 503 Big Data Management
CS 586/DS 504 Big data Analytics

Relevant Data Science courses:

DS 501 Introduction to Data Science
DS 502/MA 543 Statistical Methods for Data Science

Relevant Mathematical Sciences courses:

MA 508 Mathematical Modeling
MA 543/DS 502 Statistical Methods for Data Science
MA 510/CS 522 Numerical Methods
MA 511 Applied Statistics for Engineering and Scientists
MA 542 Regression Analysis
MA 546 Design and Analysis of Experiments
MA 550 Time Series Analysis
MA 556 Applied Bayesian Statistics

Type: Master of Science

Physics

Faculty

D.T. Petkie, Department Head and Professor; Ph.D., Ohio State University. Millimeter-wave and Terahertz sensing, spectroscopy, electromagnetic scattering and propagation, photonics, optics and imaging.
P. K. Aravind, Professor; Ph.D., Northwestern University. Quantum information theory.
N. A. Burnham, Professor; Ph.D., University of Colorado. Mechanical properties of nanostructures, instrumentation for nanomechanics.
G. S. Iannacchione, Professor; Ph.D., Kent State University. Soft condensed matter physics/ complex fluids, liquid-crystals, calorimetry, and order-disorder phenomena.
D. C. Medich, Associate Professor; Ph.D., University of Massachusetts – Lowell. Nuclear science and engineering, medical and health physics, radiation biology.
B. Pollard, Assistant Teaching Professor; Ph.D., University of Colorado Boulder. Physics Education Research with a focus on physics laboratory courses.
R. S. Quimby, Associate Professor; Ph.D., University of

Wisconsin – Madison. Optical properties of solids, laser spectroscopy, fiber optics.
L. R. Ram-Mohan, Professor; Ph.D., Purdue University. Field theory, many body problems, solid state physics, and finite-element modeling of quantum systems.
I. Stroe, Associate Teaching Professor; Ph.D., Clark University. Experimental biophysics, protein structure, dynamic, and functionality.
L. V. Titova, Associate Professor; Ph.D., University of Notre Dame. THz spectroscopy of nanomaterials for energy applications; optical excitations and ultrafast carrier dynamics in nanomaterials.
R. Trubko, Assistant Professor; Ph.D., University of Arizona. Quantum physics, Nitrogen-vacancy centers in diamond, magnetic microscopy and imaging for biosciences and geosciences, machine learning, optics.
Q. Wen, Associate Professor, Ph.D., Brown University. Experimental biophysics, mechanical properties of tissue cells and biological materials, cell-ECM interactions.
K. Wu, Assistant Professor, Ph.D., New York University. Active matter, kinesin-driven microtubules, fluid dynamics, experimental soft matter and biophysics.
R. Zekavat, Professor; Ph.D., Colorado state University. Wireless Localization and Communications, Propagation Channel Modeling, Statistical Signal Processing, Sensor Data Analysis and Machine Learning.
A. Zozulya, Professor; Ph.D., Lebedev Physics Institute. Nonlinear optics, photorefractive materials, atom pipes.

Affiliated Faculty

C. Furlong, Professor; Ph.D., WPI, 1999. MEMS and MOEMS, micro- /nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.
Y. Liu, Associate Professor; Ph.D., University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, optofluidics, fiber optic sensors, cell mechanics, biomimetics.

Research Areas

The two major areas of research in the department are: Biophysics/Soft-Matter and Nanoscience/Condensed Matter Physics, including optics and photonics.

Nanoscience/Condensed Matter

Cold atoms – Bose-Einstein Condensation of bosons and fermions, atom wave guides and interferometers.
Magnetic Solids – Magnetic impurities in semiconductors: diluted magnetic semiconductors and the onset of ferromagnetism in spintronic materials.
Nanomechanics – Mechanical properties of nanostructures, instrumentation and metrology for nanomechanics.
Photonics – Nonlinear optics, fiber optics, optical properties of rough surfaces and of thin metal films. Development of infrared fiber lasers and materials, mid-IR and FIR quantum cascade laser design and Photonic Integrated Circuits.
Quantum Information – Foundations of quantum mechanics, quantum algorithms.
Semiconductors – Optical properties of super-lattices, heterostructure laser design, spintronics in diluted magnetic semiconductors,devices.
Spectroscopy – Laser spectroscopy of impurity ions in glasses, quasi-elastic/inelastic light scattering and excitation/ modulation spectroscopy of super-lattices, thin films, surface phenomena and gas phase molecular spectroscopy.
Ultrafast optical spectroscopy – Terahertz science and technology, optical properties of nanomaterials for energy conversion.
Wavefunction Engineering – Nanostructures, finite-element modeling of quantum systems and wells, field theory.

Biophysics/Soft-Matter

Active matter – non-equilibrium statistical physics, dynamics of confined active fluids, self-organization of energy-consuming materials, self-propelled particles, self-pumping fluids, biopolymers (microtubules, actins), molecular motors (kinesin, myosin), bio-mimetic materials.
Biomaterials – hydration effects on protein dynamics, thermodynamics of proteins and DNA, self-assembly of biomaterials, dielectric relaxation spectroscopy, relaxation calorimetry, resonant ultrasound spectroscopy, studies of tissue cells, theory and simulations of bio-polymers and molecular motors.
Biomechanics – Locomotion of living organisms, cellular structure and motion, computational biophysical fluid dynamics.
Cellular biophysics – Cell mechanics and intra-cellular transport, physics of the cytoskeleton (cellular skeleton), cargo transport in cells, super-resolution imaging, correlation spectroscopy, simulations of cellular processes.
Complex Fluids – Diffusion and transport properties of complex fluids, light scattering spectroscopy of liquids and polymer melts, mesoscale simulations of liquids, capillary wave theory, theory and simulations of phase transitions in multi-component mixtures, active fluids.
Glasses – Theory and simulation, thermodynamics and relaxation dynamics.
Liquid Crystals – Thermotropic/lyotropic/ colloidal systems, phase transitions and critical phenomena, cooperative behavior and self-assembly, quenched random disorder effects, calorimetry instrumentation.

Polymers – Molecular properties at the single molecule level, polymer and bio-macromolecular solutions, surfactants, colloids.

Nuclear Science and Engineering

Health Physics: radioactive particle resuspension, effects of active dosimetry on radiation safety, development of instrumentation for neutron imaging, nuclear security, material and contaminate characterization via Neutron Activation Analysis, development of a compact neutron collimator for enhanced planar neutron flux.
Medical Physics: development of ultrahigh resolution physiological imaging with neutrons, intensity modulated brachytherapy using Yb-169, development of Gafchromic film dosimetry for uses in high-gradient brachytherapy
Radiation Dosimetry: Dosimetric analysis and calculations; Monte Carlo radiation transport and energy deposition simulations

Program of Study

The Department of Physics offers programs leading to the M.S. and Ph.D. degrees in Physics and the M.S. and Ph.D. degrees in Applied Physics with concentrations in Biophysics and Soft Condensed Matter, Medical Physics, Nanoscience and Technology, Photonics, and Radiological Sciences. The Department of Physics also offers a Master of Science program in Physics for Educators (MPED) and a Graduate Certificate in Nuclear Science and Engineering (NSE) and an accelerated B.S./M.S. program.
Research opportunities are available in experimental, theoretical, and computational studies of biophysics and soft condensed matter physics, materials science, medical physics, nanoscience, optics, photonics, atomic physics, and radiological sciences. In addition to coursework and research opportunities, professional development opportunities also exist for students interested in a career pathway in academia, industry, federal laboratories, and education. The Physics program reserves its financial aid for graduate students in the Ph.D. program.

Physics Program (Ph.D. and M.S.)

WPI Physics graduate program provides students with a broad background in the core areas of fundamental physical sciences and prepares students for careers in research in an academic, industry, or national laboratory setting. In addition to core courses, students are encouraged to acquire breadth by choosing special topics courses to complement their studies. Students carry out rigorous research in theoretical and experimental physics areas including: biophysics, condensed matter physics, optics, quantum physics, atomic, and nuclear physics. The M.S. program provides a suitable foundation for the pursuit of a Ph.D. degree in physics, or a related field, or for a career in industry immediately after graduation.

Applied Physics Program (Ph.D. and M.S.)

The Applied Physics program provides a flexible set of interdisciplinary skills to prepare students for careers at national and international laboratories, industry, education, and academia. It combines a core physics curriculum with cross-cutting research in areas at interface of physics and other scientific disciplines. Applied Physics Ph.D. and M.S. students are required to select a research concentration and a corresponding set of thematically related courses from the following five options: Biophysics and Soft Condensed Matter Physics, Medical Physics, Nanoscience and Technology, Photonics, and Radiological Sciences.

Master of Science in Physics for Educators (MPED)

The Master of Science in Physics for Educators is designed specifically for middle school, high school, and community college in-service educators. The emphasis of the program is put on physics courses designed for educators and is combined with courses in assessment and evaluation theory and a participant-designed project. The physics content courses are intended to give educators a deep but applicable understanding of physics that makes advanced physics topics easily accessible to educators and the students they teach. Topics covered will include modern physics, methods in physics and physics for citizens and leaders. Support for degree candidates extends beyond the specific coursework and projects as participants will become part of a network of physicists which ranges from local individuals to a much broader community. The program may be used to help middle and high school educators move from Initial to Professional Licensure in Massachusetts. For information about admissions and requirements, see the listing under STEM for Educators.

Graduate Certificate in Nuclear Science and Engineering (NSE)

The Graduate Certificate in Nuclear Science & Engineering requires the successful completion of 12-18 graduate credit-hours) with an overall GPA of 3.0. Credits are chosen from the NSE 510-50 course listing or by approval of the NSE Program Committee. Courses cover such topics as nuclear power, radioactivity, chain reaction physics, nuclear reactor safety, power plant design and operation, and case studies of nuclear accidents. These courses are offered on campus, and online through Corporate and Professional Education. The faculty in the certificate program hold a full-time position in a WPI academic department or are affiliated faculty approved by an academic department and NSE program review committee.

Combined B.S./M.S. Program

The Department of Physics offers a combined B.S./M.S. degree option in Physics and Applied Physics for undergraduate students currently enrolled at WPI. The university rules for B.S./M.S. programs are described in the undergraduate catalog and graduate catalog. It is recommended that the M.S. application be submitted at the beginning of the student's junior year of undergraduate study at WPI.

Admission Requirements

M.S. and Ph.D. Physics and Applied Physics Programs

For the M.S. or Ph.D. in Physics programs, a B.S. in Physics, Applied Physics or the equivalent is required for admission. The Applied Physics M.S. and Ph.D. programs also allow students to be admitted with B.S. degrees from other areas, such as engineering, materials science, or other natural sciences. Candidates not meeting this minimum academic requirement may be required to take additional undergraduate courses, which do not count towards coursework to satisfy graduate degree requirements. Well-qualified Ph.D. candidates entering with an M.S. degree in Physics, Applied Physics or its equivalent will be considered by the Physics Department Graduate Committee (PDGC) for admission with Ph.D. 60 status, as described in Degree Requirements section under General Requirements for the Doctorate. The application to any program must include a Statement of Purpose describing the motivation for pursuing a graduate degree in Physics or Applied Physics at WPI and identifying one or more faculty members as potential research advisors. Students applying to the Applied Physics program are required to identify a specific concentration. Applicants should contact faculty directly to learn about their research. Transcripts from every previously attended college or university, a CV, and three letters of reference are also required.

MPED and NSE Programs

A B.S. in Physics is preferred. However, applicants with comparable backgrounds will also be considered.

M.S. in Physics or Applied Physics

The M.S. degree in Physics or Applied Physics requires completing 30 graduate credit-hours; applicants must specify their intention to pursue either a thesis or non-thesis option. All full-time students are required to register for the zero-credit graduate seminar (PH 580) each term. The thesis option requires a minimum of 15 credit-hours of coursework as described below, a minimum of 6 hours of thesis research (PH 599) and the completion, public seminar presentation, and defense of an M.S. thesis. The thesis option will require that a thesis committee be formed one year prior to the student's expected graduation date. This committee will be formed by the student and his/her research advisor and will consist of three faculty members (including the advisor, who will be responsible for providing mentoring to the student and for overseeing the progress of the student towards a successful completion of their degree). The research advisor may not be the chair of this committee.

Alternatively, students may pursue a non-thesis option which requires the student to complete a minimum of 24 credit-hours of graduate coursework from the courses listed below, and a minimum of 6 hours of directed research (PH 598). Specific course requirements for the M.S. in Physics or Applied Physics are as follows:

- M.S. in Physics: 15 credits are required in core courses (PH 511, PH 514, PH 515, PH 522, and PH 533). The remaining 15 credits are electives, thesis research, or directed research; courses taken outside of the department must be approved by the PDGC.
- The M.S. in Applied Physics:
- Biophysics/Soft Condensed Matter Concentration: Required Core Courses: PH 511, PH 522; PH 562. Students are also required to complete additional coursework (minimum of 6 credit hours for thesis option and a minimum of 15 credit hours for non-thesis option) in elective courses: PH 563, PH 533, PH 514, PH 541, PH 554, PH 561, PH 571, BME 555, BME 564, BME 583, CHE 541 or other courses approved by PDGC.
- Medical Physics Concentration: Two of the core physics courses (PH 511, PH 514, PH 515, PH 522, and PH 533), NSE 515, NSE 530, NSE 560, NSE 570, NSE 580, NSE 585, an undergraduate or graduate Anatomy and Physiology course.
- Nanoscience and Technology Concentration: Required Core Course: PH 514, and PH 511 or PH 533. Students are also required to complete additional coursework (minimum of 9 credit hours for thesis option and a minimum of 18 credit hours for non-thesis option) in elective courses: PH 511 or PH 533, PH 515, PH 522, PH 541, PH 554, PH 561, MTE 575, MTE 509, MTE 532, CH 516, CH 554, or other courses approved by the PDGC.
- Photonics Concentration: Required Core Courses: PH 514, PH 533, PH 544. Students are also required to complete additional coursework (minimum of 6

credit hours for thesis option and a minimum of 15 credit hours for non-thesis option) in elective courses: PH 511, PH 515, PH 541, PH 548, PH 554, PH 561, PH 571, ME 5225, ME 5301, BME 583 or other courses approved by PDGC.
- Radiological Sciences Concentration: Required Courses: Two of the core physics courses (PH 511, PH 514, PH 515, PH 522, and PH 533), NSE 515, NSE 530, NSE 560. Students who are pursuing non-thesis option are required to complete a minimum of 9 credit-hours of PH or NSE graduate courses or other courses approved by the PDGC.

Changing of M.S. Option:

Students may petition the PDGC to switch from a non-thesis to a thesis option. Such petition must include justification, and a letter of support from a potential M.S. thesis advisor. Students may also petition PDGC for switching from a thesis to a non-thesis option, switching between Physics and Applied Physics programs, and changes in Applied Physics concentration. Petitions will be reviewed in consultation with student's advisor, when appropriate.

Type: Master of Science

Ph.D. in Physics or Applied Physics

Students in the Physics or Applied Physics Ph.D. program are required to complete 90 graduate credit hours of coursework and a minimum of 30 credits of research (Directed Research, PH 598 or Ph.D. Dissertation, PH 699). These students also must complete and defend their Ph.D. thesis. Courses taken to satisfy M.S. degree requirements will be counted toward the Ph.D. credit requirements, but completion of an M.S. degree is not required. All full-time students are required to register for the zero-credit graduate seminar (PH 580) each term.

Students entering the Physics or Applied Physics Ph.D. program who already have been granted an M.S. degree in Physics, Applied Physics, or Engineering Physics may be promoted to Ph.D. 60 status. Ph.D. 60 students are required to complete 60 graduate credit hours, including a minimum of 30 credits of research (Directed Research, PH 598 or Ph.D. Dissertation, PH 699). Coursework requirements for the students in Ph.D. 60 status will be determined by the PDGC upon review of student's previous graduate coursework.

The PDGC reviews each student's academic work on an annual basis, and the committee and the academic or research advisor may require additional coursework to address specific deficiencies in the student's background. Students must maintain a minimum of a 3.0 GPA to be in good standing. One year of residency in the program is required.

A description of other Ph.D. program requirements follows below.

Comprehensive Written Examination

Students entering the Ph.D. program in Physics or Applied Physics are required register for and pass the Comprehensive Written Examination (PH 798) no later than the end of their second year. No more than 3 attempts to pass this exam are allowed. This exam is offered twice a year during Fall and Spring semesters. The exam consists of four areas depending on the degree program, as follows:

- Ph.D. in Physics: Classical Mechanics; Quantum Mechanics; Electrodynamics; Thermodynamics and Statistical Physics
- Ph.D. in Applied Physics:
    - Biophysics and Soft Condensed Matter Concentration: Classical mechanics; Statistical Mechanics; Biophysics and Soft Condensed Matter; and an additional area chosen in consultation with the student's thesis committee and approved by PDGC (examples: Microscopy and Imaging, Computational Biophysics, AFM)
    - Medical Physics Concentration: Radiation Biology, Health Physics, Diagnostic Medical Physics, Radiation Therapy Physics.
    - Nanoscience and Technology Concentration: Quantum Mechanics; Classical Mechanics or Electrodynamics, and two additional areas such as another core Physics area, Solid State Physics, Atomic Force Microscopy, Nanomaterials, Spectroscopy, or an alternative topic chosen in consultation with the student's thesis committee and approved by PDGC
    - Photonics Concentration: Quantum Mechanics; Electrodynamics; Photonics, and additional area chosen in consultation with the student's thesis committee and approved by PDGC
    - Radiological Sciences Concentration: Nuclear Instrumentation, Health Physics, Radiation Biology and a core physics area chosen in consultation with the student's thesis committee and approved by the PDGC

Ph.D. Qualifying Examination

Students enrolled in the Physics or Applied Physics Ph.D. program are required to register and pass, no later than the end of the third year after formal admittance to the Ph.D.

program, the Ph.D. Qualifying Exam (PH 799). Here, the student is required to write and defend an original research proposal before a committee representative of the area of their specialization, approved and appointed by the PDGC. The students are allowed only two attempts to pass this exam. The examination is used to evaluate the ability of the student to pose meaningful scientific questions, to propose experimental or theoretical methods for answering those questions, and to interpret the validity and significance of probable outcomes of these theoretical conjectures, models or experiments. The committee will consist of a minimum of three physics faculty members including the advisor, and at least one faculty member from outside the department, and will administer and evaluate the exam. The research advisor may not be the chair of this committee. The students are also required to take and pass a one-credit scientific writing course (PH 585) prior to their first attempt at taking the Ph.D. Qualifying Exam.

Ph.D. Dissertation

To fulfill the final Ph.D. degree requirement, the candidate must submit and defend a satisfactory dissertation to the dissertation committee formed in consultation with the research advisor and approved by the PDGC. This committee will consist of a minimum of three physics faculty members including the advisor, and at least one faculty member from outside the department. The research advisor may not be the chair of this committee.

Transferring between Ph.D. program options:

Students may petition the PDGC to switch between a Physics and Applied Physics programs, or to change the concentration. Such petition must include justification, and a letter of support from student's advisor.

Type: Ph.D.

Physics for Educators

Master of Science in Physics for Educators (MPED)

For a complete overview of degree requirements, please see STEM for Educators section.

Type: Master of Science

Robotics Engineering

Faculty

J. Xiao, Professor and Department Head; Ph.D., University of Michigan. Robotic manipulation and motion planning, artificial intelligence, haptics, multi-modal perception.
M. Agheli, Assistant Teaching Professor, Ph.D., Worcester Polytechnic Institute (WPI), 2013. Soft Robotics, Legged Robotics
N. Bertozzi, Senior Instructor; M. S. Northeastern University. Engineering design graphics, active learning/ flipped classrooms, program and course student outcomes assessment.
B. Calli, Assistant Professor, Ph.D., Delft University of Technology, 2015. Robotic manipulation, robot vision, machine learning, dexterous manipulation, environmental robotics.
L. Fichera, Assistant Professor; Ph.D., University of Genoa/ Italian Institute of Technology. Continuum robotics, medical robotics, surgical robotics, image-guided surgery, laser-based surgery, medical devices
G. S. Fischer, Professor, Ph.D., Johns Hopkins University. Medical cyber- physical systems, surgical robotics, image-guided interventions, assistive technology, robot modeling and control, automation, sensors and actuators.
J. Fu, Assistant Professor; Ph.D., University of Delaware, 2013. Control theory, formal methods, machine learning.
M. A. Gennert, Professor; Sc. D., Massachusetts Institute of Technology 1987. Image processing, image understanding, artificial intelligence, robotics.
G. C. Lewin, Assistant Teaching Professor and Robotics Engineering Associate Head; Ph.D., University of Virginia, 2003. Systems integration, mobile robotics, mechatronics, sensors and control.
Z. Li, Assistant Professor; Ph.D., University of California, Santa Cruz, 2014. Human-robot interaction, Motion coordination of cyber-human system, Nursing and Rehabilitation Robots.
W. R. Michalson, Professor; Ph.D., Worcester Polytechnic Institute. Satellite navigation, real-time embedded computer systems, digital music and audio signal processing, simulation and system modeling.
M. Nemitz, Assistant Professor, Ph.D. The University of Edinburgh. Robotic soft materials, magnetism, fluidics, machine learning.
C. D. Onal, Associate Professor; Ph.D. Carnegie Mellon University, 2009. Soft robotics, printable robotics, origami-inspired robotics, bio-inspiration, control theory, human augmentation.
C. Pinciroli, Assistant Professor, PhD., Université Libre de Bruxelles, Belgium, 2014. Swarm robotics, software engineering, multi-agent systems, human- swarm

interaction, programming languages.
M. B. Popovic, Assistant Research Professor; Ph.D. Boston University. Human neurosensory-motor organization, soft robotics, wearable robotics, assistive robotics, human augmentation systems.
X. Zeng, Assistant Professor; Ph.D., Ohio State University, 2016. Connected and automated vehicles, mobility cyber-physical systems, intelligent transportation systems, and optimal control.
H. Zhang, Assistant Professor; Ph.D., Johns Hopkins University, 2017. Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Associated Faculty

E.O. Agu, Associate Professor; PhD., Massachusetts, 2001. Computer graphics, wireless networking, mobile computing and mobile health.
S. Barton, Associate Professor; Ph.D. University of Virginia, 2012. Human- robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.
C. A. Brown, Professor; Ph.D., University of Vermont, 1983. Surface metrology, machining, grinding, mechanics of skiing, axiomatic design.
C. Furlong, Professor; Ph.D., Worcester Polytechnic Institute. MEMS and MOEMS, micro-/nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.
G.R. Gaudette, William Smith Dean's Professor of BME; PhD. SUNY Stony Brook; Cardiac biomechanics, myocardial regeneration, biomaterial scaffolds, tissue engineering, stem cell applications, optical imaging techniques, cellular agriculture, crossing biological kingdoms.
X. Huang, Professor; Ph.D., Virginia Tech. Reconfigurable computing, VLSI integrated circuits, networked embedded systems
D. Korkin, Associate Professor, PhD., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.
Y.S. Liu, Assistant Professor; PhD. University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, optofluidics, fiber optic sensors, cell machanics, biomimetics.
P. Radhakrishnan, Assistant Teaching Professor; PhD., The University of Texas at Austin, 2014. Automated design and manufacturing; entertainment and medical engineering; optimization, machine learning and software development; kinematics, dynamics and design education.
C. L. Sidner, Research Professor; Ph.D., Massachusetts Institute of Technology, 1979. Discourse processing, collaboration, human-robot interaction, intelligent user interfaces, natural language processing, artificial intelligence.
J.Skorinko, Professor; Ph.D. University of Virginia, 2007. Social psychology, decision-making, interpersonal interactions.
E. Solovey, Assistant Professor, Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.
J. Stabile, Instructor, MSME, University of Arizona; MEEE, University of Colorado. High efficiency small speaker systems for personal audio. Motor and actuator design, high bandwidth structural design with finite element analysis, force balanced transducer design, and planar acoustic arrays. 3D additive creation of planar electromagnetic actuators.
A. M. Wyglinski, Professor, Ph.D., McGill University. Wireless communication systems engineering, vehicular technology, cognitive radio, software-defined radio, autonomous vehicles, wireless spectrum, vehicular security, cyber-physical systems.
Z. Zhang, Assistant Professor; Ph. D., Oxford Brookes University, 2013. Computer vision and machine learning, object recognition/detection, data-efficient learning, with applications; deep learning, optimization.
Y. Zheng, Assistant Professor; PhD., University of Michigan, 2016. Advanced and biomedical manufacturing, medical device design, tissue mechanics, biomedical machining process and modeling, catheter-based surgical devices, medical simulation, vascular ultrasound imaging, abrasive machining processes for biomedical and ceramic materials.

Program of Study

M.S. Program

The Robotics Engineering Department offers the M.S. degree with thesis and non-thesis (course-work only) options. The department strives to educate men and women to:

- Have a solid understanding of the fundamentals of Robotics Science, Engineering, and Systems.
- Have an awareness of the management and systems contexts within which robotic systems are engineered.
- Develop advanced knowledge in selected areas of robotics, culminating in a capstone research or design experience.

Admission Requirements

Students will be eligible for admission to the program if they have earned an undergraduate degree in Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering or a related field from an accredited university consistent with the WPI graduate catalog. Admission will also be open to qualified WPI students who opt for a five-year Bachelors-Masters program, with the undergraduate major in Computer Science, Electrical & Computer Engineering, Mechanical Engineering, Robotics Engineering or a related field. Admission decisions will be made by the Robotics Engineering Graduate Program Committee based on all of the factors presented in the application.

Robotics Engineering Laboratories

Adaptive and Intelligent Robotics (AIR) Lab

Professor Jing Xiao

The AIR Lab is located at 301 (3rd floor) of 85 Prescott Street. Research at the AIR Lab is focused on robotic systems that can best adapt to unknowns, uncertainties, and changes in the working environments, through real-time perception, planning, learning, and execution in seamless synergy. Interested areas include robotic assembly, manipulation, and navigation in human-centered environments, with different kinds of manipulators, from articulated to continuum/soft robots, and in a wide range of applications, including assembly, additive manufacturing, material handling, maintenance and repair, medical and healthcare, manufacturing, and services. Further information is available at https://wp.wpi.edu/airlab/home/

Automation and Interventional Medicine (AIM) Lab

Professor Gregory Fischer

The Automation and Interventional Medicine Laboratory Robotics Research Laboratory (AIM Lab) is located at Gateway Park. The primary focus of projects in the AIM Lab is medical robotics including: robotic surgery, image-guided surgery, MRI-compatible mechatronics, rehabilitation robotics, socially assistive robotics, and biofabrication. The lab contains student workstations, equipment for mechanical and electrical design, construction, configuration, and testing of robots, control systems, and automated test fixtures, including state-of-the-art electronics testing and micro-electronics assembly equipment and supplies. An optical tracker is available for motion capture. The lab houses MRI robot controllers developed in the AIM Lab and custom control electronics for high precision control of piezoelectric motor drive waveforms and corresponding robotic system testbeds. A da Vinci Research Kit (dVRK) surgical robot is also available in the lab which includes the Intuitive Surgical robot with custom open control systems. Access to medical imaging in a clinical site is available through collaboration with the nearby UMass Medical School and with the Brigham and Women's Hospital. The research in the AIM Lab is directed by Prof. G. Fischer. Further information can be found at http://aimlab.wpi.edu/.

Cognitive Medical Technology (COMET) and Robotics Laboratory

Professor Loris Fichera

Research in the COMET Laboratory focuses on the development of smart medical devices and robots. Specific focus areas include autonomous and semi-autonomous surgical robotics, continuum (continuously flexible) surgical instruments and image-guided surgery. The lab features state-of-the-art experimental equipment, including two surgical laser systems (10,600 and 532 nm), an NDI Aurora electromagnetic tracker, a FLIR A655sc thermal camera and a Franka Emika 7-DoF Panda manipulator. The lab has research collaborations with clinical partners at Brigham and Women's Hospital (Boston, MA), Vanderbilt University Medical Center (Nashville, TN) and the Children's National Hospital (Washington, D.C.). The lab is located in room 4832 at 50 Prescott St. and is directed by Prof. L. Fichera. Further information is available at https://comet-lab.github.io/

Computational Intelligence and Bionic Robotics (CIBR)

Professor Jie Fu, Professor Zhi Li, and Professor Carlo Pinciroli

CIBR lab is a joint lab among Professors Jie Fu, Zhi Li and Carlo Pinciroli. Our research focus is to bring a joint force between control theory, machine learning, and robotics to achieve two major objectives: First, by leveraging learning-based control design, we aim to develop algorithms to achieve provably safe, adaptive, and robust performance in autonomous systems in the presence of uncertain and dynamical environments. Second, we aim to build the algorithmic foundations for bionic robotics that facilitate seamless collaboration between humans and robots, with applications to advanced medical, space, and military robotics.

Control and Intelligent Robotics Laboratory (CIRL)

Professor Jie Fu

The Control and Intelligent Robotics Laboratory (CIRL) is located at 85 Prescott Street (Gateway Park). The primary focus is for developing theory and algorithms for verifying and synthesizing intelligent and (semi-) autonomous systems through the integration of control theory, machine learning, game theory, and formal methods. Specifically, we aim to construct trustworthy and adaptive systems with complex decision-making capabilities in dynamic, uncertain environments. Research in CIRL lab is directed by Prof. Jie Fu. Further information can be found at http://labs.wpi.edu/cirl/.

Human-inspired Robotics (HIRO) Lab

Professor Zhi Li

The Human-inspired Robotics lab aims to achieve the high-level synergy of human and robotic systems. Specifically, we apply the motion control strategies discovered in human movement science to the design of robot automation. Our research primarily focuses the wearable robots and humanoid robots that augment and collaborate with human workers in healthcare, space, warehouse applications. Our current projects include: perception-action coordination of cyber-human system, computational modeling of physical human-robot interaction, high level learning and planning of human-robot collaboration. Further information is available at http://labs.wpi.edu/hiro/

Manipulation and Environmental Robotics (MER) Lab

Professor Berk Calli

The Manipulation and Environmental Robotics Lab primarily focuses on enhancing manipulation capabilities of robots. The research integrates visual feedback, advanced control methods, active vision framework, machine learning algorithms and intelligent mechanical design to achieve robust and dexterous robotic systems. Such systems are essential for executing grasping and manipulation tasks in unstructured environments, including homes, offices, modern warehouses, and collaborative manufacturing stations. One of the main themes of the lab is environmental robotics, i.e. utilizing robots to solve environmental problems such as waste management issues and recycling efficiency. The lab is directed by Prof Berk Calli. Further information is available at https://wp.wpi.edu/merlab/

Medical Frontier Ultrasound Imaging and Robotic Instrumentation (FUSION) Lab

Professor Haichong (Kai) Zhang

Medical FUSION (Frontier Ultrasound Imaging and Robotic Instrumentation) Lab focuses on the interface of medical robotics, sensing, and imaging, and to develop robotic assisted imaging systems as well as image-guided robotic interventional platforms, where ultrasound and photoacoustic (PA) imaging are two key modalities to be investigated and integrated with robotics. The scope of innovation focuses on medical robotics, sensing and imaging for (1) co-robotic imaging, where a robotic component is essential to reduce user-dependency in ultrasound scanning, to build an image with higher resolution and contrast, and to miniaturize and simplify imaging platform and (2) PA-based functional image-guided interventions that give additional information for surgical guidance with high sensitivity and specificity. Further, we will also tackle (3) mathematical and algorithmic challenges behind computer assisted interventions such as hand-eye calibration to support these deployments. The developed systems will synergistically improve both image quality and surgical accuracy and specificity towards diagnostic and interventional applications.
https://medicalfusionlab.wordpress.com/

Novel Engineering of Swarm Technologies (NEST) Lab

Professor Carlo Pinciroli

The Novel Engineering for Swarm Technologies (NEST) Laboratory focuses on the design of algorithms, machine learning algorithms, and software tools for swarm robotics and human interaction, with applications to disaster recovery and firefighting. The lab offers a swarm of 10 Khepera IV robots (along with extension modules such as grippers and LIDARs) and 100 Kilobots. In addition, the lab has a dedicated experimentation area equipped with a Vicon motion capture system comprising 10 cameras (2.2 Megapixel resolution at 330 frames per second, with varifocal lenses and an IR strobe), a dedicated 1 Gb network connected to a workstation through Vicon Lock+, and the latest version of Vicon image analysis software (Vicon Nexus Standalone, Vicon BodyBuilder, Tracker 3.0 Standalone). The research is conducted in collaboration with Amazon Robotics and Mathworks. The lab is located in 85 Prescott Street and is directed by Prof. Carlo Pinciroli. Further information is available at https://www.nestlab.net.

PracticePoint

Professor Gregory Fischer

PracticePoint is a Massachusetts Technology Collaborative (Mass Tech) supported R&D center that seeks to improve healthcare technologies and develop new medical cyber-physical systems. PracticePoint provides an agile and scalable, collaborative research facility empowering public and private universities, research institutions, industry and innovators to incorporate cyber-physical systems into medical devices and equipment that will improve performance, security, accuracy, timeliness, costs and outcomes in human healthcare. PracticePoint fosters collaborations among its affiliates through state-of-the-art clinical care test beds, secured project pods, collaboration suites and shared tool bays. The point-of-practice environments including: medical imaging coupled with a hybrid operating room suite (including an MRI scanner), a controlled care environment (reconfigurable as ICU, exam room, and recovery room), rehabilitative care suites (including motion capture and rehab equipment), and a residential setting (highly instrumented mock home environment). These point-of-practice care suites are co-located we will have advanced manufacturing (including CNC machining, 3D printing, laser cutting), electronics assembly and test equipment, and build areas. The facility also comprises office spaces for faculty and graduate students, individual research group lab spaces, and reconfigurable "lab pods." Further information can be found at http://practicepoint.org.

Robotic Soft Matter (RSM) Group

Professor Markus Nemitz

The Robotic Soft Matter Group focuses on robotizing soft materials to create programmable matter that can change its shape. By activating otherwise passive materials, we can build robots that can adapt to their environment and serve several purposes at once. Located on the third floor at 85 Prescott, the group addresses the fundamental and technical challenges in the creation, manufacture, and modeling of programmable soft matter. In particular, we investigate shape-changing materials and mechanisms, embedded sensors for shape sensing, and control strategies for shape-changing. The lab collaborates with WPI's Lab for Education and Application Prototypes (LEAP), accessing 2,000 square feet of cleanroom and laboratory facilities equipped with state-of-the-art equipment including multi-material printers, inkjet printers for the fabrication of stretchable and flexible circuits, submicron assembly and positioning systems, and plasma systems. Prof. Markus Nemitz is the director of the Robotic Soft Matter Group. Open projects and positions can be found at: www.roboticsoftmattergroup.com

Robotics, Mobility, and Cyber- Physical Systems Laboratory

Professor Xiangrui Zeng

Robotics, Mobility, and Cyber-Physical Systems Lab focuses on developing and applying data-enhanced intelligent control algorithms to improve the performance of a variety of cyber-physical systems, especially those involve robotics and mobility. The research combines optimal control and machine learning with applications in robotics, connected and automated vehicles, as well as intelligent transportation systems. The ultimate goal is to design comprehensive tools utilizing all available data to achieve optimal performance for cyber-physical systems.

WPI Humanoid Robotics Laboratory (WHRL)

Professors Mahdi Agheli, Michael Gennert

The WPI Humanoid Robotics Laboratory in Washburn 108 conducts research into humanoid locomotion, perception, control, planning, and user interfaces. WHRL features WARNER (WPI's Atlas Robot for Non-conventional Emergency Response) and a custom-designed humanoid platform. We are working on many exciting research projects: 2-handed manipulation, handing objects between Atlas and a human, generic humanoid software that can operate on Atlas and Valkyrie, designing a low-cost humanoid, competing in the NASA Space Robotics Challenge, and more. Advanced software includes Gazebo simulator, RViz visualization software, MoveIT! trajectory planner, TrajOpt trajectory optimizer, ROS middleware, and the OpenCV and Point Cloud Library packages.

WPI Popovic Labs

Professor Marko Popovic

Researchers study physics, biomechanics and robotics with a goal to answer how living systems function and to synthesize systems that have resembling architecture and functionality and/or may improve life. Numerous biomechatronics projects include advanced prosthetics, braces, exoskeletons, exo-musculatures, exo-suits, physical therapy and assistive devices. Researchers also work on bioinspired robots, physical intelligence, new actuators, transmission mechanisms, valves, intelligent structural elements, and novel propulsion methods. Through close connection with industry partners a lot of research activity is focused on novel industrial robotics. Lab houses various equipment, manufacturing tools as well as one of the most advanced 3D printers on campus. Lab is also home to big dual arm Yaskawa robot. Learn more at http://users.wpi.edu/mpopovic/

WPI Robot Communications and Navigation Laboratory

Professor William Michalson

The Robot Communications and Navigation Laboratory at 85 Prescott street conducts research into the navigation of and communications with air, land and sea robots in indoor and outdoor locations. The laboratory has platforms for land robots as well as several rotorcraft and sailing platforms and has competed in intelligent ground vehicle and sea vehicle competitions.

WPI Soft Robotics Laboratory

Professor Cagdas Onal

The Soft Robotics Laboratory is located in HL 127, and supports personnel and equipment required for the design, development, and control of next-generation soft, flexible, and semi-rigid robotic systems. Projects in the lab include studying and developing soft robotic snakes, octopus arms, origami-inspired hexapods, tentacles, flying robots, wearable haptic interfaces, human-robot interaction, and multi-robot systems.

Equipment in the Soft Robotics lab includes tools for design, fabrication, experimentation, and analysis, including an Epilog Zing 24 CO2 laser cutter, a dual nozzle 3D printer, a motion capture area, various semi-rigidware packages for mechanical and electronic design, a full custom-made flexible circuit fabrication and assembly equipment suite, a large-workspace optical microscope, an elastomeric fabrication workbench, and various data acquisition and analysis systems. The lab currently supports research activities in elastomeric robotic systems, printed circuit and sensor manufacturing, origami-inspired foldable systems, assistive soft robotic monitoring, bio-inspired stereo vision, and prosthetic robotics. Research in the Soft Robotics Laboratory is directed by Prof Onal. Further information can be found at http://softrobotics.wpi.edu/.

B.S./M.S. in Robotics Engineering

WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelors-Masters program. This 12 credit overlap can be achieved through the following mechanisms:

- Up to 12 graduate credits in RBE, CS, ECE, or ME taken by the student may be counted towards meeting the engineering/science/ elective requirements of the student's undergraduate major, subject to approval by his/her major department.
- Up to 4 credits (2/3 undergraduate units) of 4000-level undergraduate courses taken by the student in his/her undergraduate major program may be counted towards the requirements of the Masters Degree in Robotics Engineering if they can be placed in one of the requirement categories listed above and are approved by the Robotics Engineering Graduate Program Committee.
- Up to 3 credits (1/2 undergraduate unit) can be earned towards fulfillment of the thesis requirement by double counting a Major Qualifying Project, provided that:
    - the MQP involves substantial use of Robotics Engineering at an advanced level,
    - the thesis research is a continuation or extension of the MQP work,
    - the student satisfies the thesis requirement by completing at least 6 additional credits of RBE 599 Thesis Research, and the thesis advisor and Robotics Engineering Graduate Program Committee approve the double counting.

MQP work may not be double-counted toward the non-thesis option.

Type: B.S./M.S.

Certificate in Robotics Engineering

The Graduate Certificate in Robotics Engineering includes the following requirements:

Type: Certificate

Core (3 credits)

Item #	Title	Credits
RBE 500	Foundations of Robotics	3

Depth (9 credits)

Courses listed below OR 9 credits of thematically-related RBE graduate-level coursework with RBE Graduate Program Committee approval.

Item #	Title	Credits
ME 501/RBE 501	Robot Dynamics	3
RBE 502	Robot Control	3
SYS 501	Concepts of Systems Engineering	3

Elective (3 credits)

Elective graduate coursework in Math, Science or Engineering with advisor approval.

M.S. in Robotics Engineering

The M.S. program in Robotics Engineering requires 30 credit hours of work. Students may select a non-thesis option, which requires a 3-credit capstone design/ practicum, or a thesis option which requires a 9-credit thesis. All entering students must submit a plan of study identifying the courses to be taken and a prospective project topic before the end of the first semester in the program. The plan of study must be approved by the student's advisor and the RBE Graduate Program Committee, and must include the following minimum requirements:

Type: Master of Science

1. Robotics Core (15 credits)

At least 15 credits are needed. Any additional credits accrued from these courses will be counted as Electives.

Students may apply to substitute the RBE 500 requirement with credits from more advanced RBE graduate courses other than RBE 594, RBE 596, RBE 597, RBE 598, RBE 599 and RBE 699. This requires taking an equivalent course/ training prior to starting to the graduate program at WPI, and the students are required to submit a petition to the RBE Graduate Program Committee for approval. Such approvals must be filed with the Registrar within one year of the date of matriculation in the program.

Foundations (9 credits)

Item #	Title	Credits
RBE 500	Foundations of Robotics	3
ME 501/RBE 501	Robot Dynamics	3
RBE 502	Robot Control	3

Core (6 credits)

Any RBE 500+ other than the above.

2. Engineering Context (3 credits):

3 credits hours selected from the following courses:

Item #	Title	Credits
ETR 500	Entrepreneurship and Innovation	3
ETR 593	Technology Commercialization	3
MIS 576	Project Management	3
OBC 506	Leadership	3
BUS 546	Managing Technological Innovation	3

3. Capstone/Thesis (3-9 credits)

A 3 credit hour capstone experience or a 9 credit hour thesis.

4. Electives (3-9 credits)

Sufficient course work selected from courses at the 500 level or above in Science, Engineering, or Business to total 30 credit hours with the approval of the student's advisor on the Plan of Study. Courses at the 4000 level may also be taken as electives in exceptional circumstances with the additional prior approval of the RBE Graduate Program Committee. The RBE 5900 (internship) course can be taken for maximum of 1 credit per semester and a maximum of 3 credits per degree.

Thesis Option

The M.S. thesis consists of 9 credit hours of work, normally spread over at least one academic year. A thesis committee will be set up during the first semester of thesis work. This committee will be selected by the student in consultation with the major advisor and will consist of the thesis advisor, who must be a full-time WPI RBE faculty member, and two other faculty members, at least one of whom is a WPI RBE faculty member, whose expertise will aid the student's research program. An oral presentation before the Thesis Committee and a general audience is required. In addition, all WPI thesis regulations must be followed.

Non-Thesis Option

As an alternative to a 9-credit research-based thesis, students may elect a 3-credit capstone from the following options:

- Capstone Project Experience in Robotics Engineering (RBE 594),
- Robotics Engineering Practicum (RBE 596),

or

- Directed Research (RBE 598).

All of the non-thesis options must demonstrate significant graduate-level work involving Robotics Engineering, include substantial analysis and/or design, and conclude with a written report and public presentation.

The Capstone Project Experience in Robotics Engineering (RBE 594) is a project-based course that integrates theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Robotics Engineering curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Robotics Engineering profession. The project must include substantial analysis and/or design, and conclude with a written report and public presentation.

The Robotics Engineering Practicum (RBE 596) provides students an opportunity to put into practice the principles that have been studied in previous courses. It will generally be conducted off campus and will involve a real-world robotics-engineering situation. Overall conduct of the practicum will be supervised by a WPI RBE faculty member; an on-site liaison will direct day-to-day activity. For a student from industry, the practicum may be sponsored by his or her employer. The project must include substantial analysis and/or design related to robotics engineering and will conclude with a public presentation and substantial written report submitted to the advisor and on-site liaison.

The Directed Research (RBE 598) option provides a research-oriented means to satisfy the capstone requirement. The student and research advisor will agree on the specific topics and deliverables on a per-project basis. The project must include substantial research, analysis and/or design related to robotics engineering and will conclude with a substantial written report and public presentation. The research advisor of the RBE 598 course must be affiliated with the RBE Department.

Transfer Credit

A student may petition for permission to use graduate courses taken at other accredited, degree-granting institutions to satisfy RBE graduate degree requirements. A maximum of 12 graduate credits, with a grade of B or better, may be satisfied by courses taken elsewhere and not used to satisfy degree requirements at other institutions. Petitions are subject to approval by the RBE Graduate Program Committee, and are then filed with the Registrar. Transfer credit will not be allowed for undergraduate-level courses taken at other institutions. In general, transfer credit will not be allowed for any WPI undergraduate courses used to fulfill undergraduate degree requirements; however, note that there are exceptions in the case of students enrolled in the B.S./M.S. program.

A student with one or more WPI master's degrees who is seeking an RBE master's degree from WPI may petition to apply up to 9 prior credits toward satisfying requirements for the subsequent degree. Petitions are subject to approval by the RBE Graduate Program Committee. Students who take graduate courses at WPI prior to formal admission to the RBE graduate program may petition to apply up to 9 graduate credits to fulfill the RBE graduate degree requirements. Once again, petitions are subject to approval by the RBE Graduate Program Committee.

Ph.D. in Robotics Engineering

The Ph.D. program in Robotics Engineering strives to educate men and women to: • Have an advanced understanding of Robotics Science, Engineering, and Systems.. • Apply tools and concepts from Management and Systems Engineering to realize robotics systems and exercise professional leadership. • Make significant research contributions in selected areas of robotics.

Type: Ph.D.

Admission Requirements

Students will be eligible for admission to the program if they have earned an undergraduate or graduate degree in Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, Robotics Engineering, or a related field from an accredited university. Applicants must supply a Statement of Purpose, three Letters of Recommendation, and Graduate Record Examination scores. The GRE requirement may be waived for WPI students and alumni, or at the discretion of the Robotics Engineering Graduate Students will be eligible for admission to the program if they have earned an undergraduate or graduate degree in Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, Robotics Engineering, or a related field from an accredited university. Applicants must supply a Statement of Purpose, three Letters of Recommendation, and Graduate Record Examination scores. The GRE requirement may be waived for WPI students and alumni, or at the discretion of the Robotics Engineering Graduate

Degree Requirements

The Ph.D. program in Robotics Engineering requires 60 credit hours of work beyond the M.S. degree or 90 credit hours beyond the B.S degree. Coursework must include 3 credit hours of Management or Systems Engineering courses at the 500 level or above. This requirement may be satisfied as part of the M.S. in Robotics Engineering or other M.S. program. All entering students must submit a plan of study identifying the courses to be taken and a prospective research area before completing more than 9 graduate credits. The plan of study must be approved by the student's academic advisor and submitted to the RBE Graduate Program Committee, and must include the following minimum requirements:

For students entering with an M.S., the 60 credits shall be distributed as follows:

1. Coursework, including Special Topics and Independent Study (12 credits). If not already included in the M.S. degree, the credits must include 3 credit hours of Management courses at the 500 level or above, or 3 credit hours of Systems Engineering courses at the 500 level or above.
2. RBE 699 Dissertation Research (30 credits).
3. Other. Additional coursework, Independent Study, RBE 598 Directed Research or RBE 699 Dissertation Research (18 credits).

For students entering with a B.S., the 90 credits shall be distributed as follows:

1. RBE M.S. Degree Requirements (30 credits).
2. Coursework, including Special Topics and Independent Study (12 credits).
3. RBE 699 Dissertation Research (30 credits).
4. Other. Additional coursework, Independent Study, RBE 598 Directed Research or RBE 699 Dissertation Research (18 credits).

Doctoral Qualifiers

The Doctoral Qualifiers evaluate each student's level of academic preparation. The Doctoral Qualifiers consist of four topic qualifiers: Technical, Writing, Speaking, and Research. The requirements for each qualifier are described in the Graduate Regulations on the RBE website https://www.wpi.edu/academics/departments/robotics-engineering. Doctoral students must successfully complete the Doctoral Qualifiers before 1) completing 30 credits towards the Ph.D. for students entering with M.S., or 60 credits towards the Ph.D. for students entering with B.S., and 2) before completing 18 credits of directed research. Advancement of the student into Ph.D. candidacy is contingent upon successful completion of the Doctoral Qualifiers. Upon successful completion of the Doctoral Qualifiers, the doctoral student advances to Ph.D. candidacy. Upon failing any topic qualifier, the student may retake the failed topic qualifier one additional time. Failing any topic qualifier twice results in the dismissal from the Robotics Engineering doctoral program. However, students can petition the RBE Graduate Program Committee to review their case. After reviewing the case, the committee can decide to let the student take the qualifier one additional time.

Dissertation

Dissertation Committee

Within one semester after the successful completion of the Doctoral Qualifiers, the student, in consultation with the Research Advisor, assembles a Dissertation Committee. The committee consists of the Research Advisor and three additional members, at least one of whom must be from outside the WPI RBE Program. The Dissertation Committee is responsible for approving the Dissertation Proposal and the Dissertation.

Dissertation Proposal

The Dissertation Proposal describes the student's proposed research. The Dissertation Proposal should be sufficiently detailed to convince the Dissertation Committee of the student's understanding of the problem domain along with the significance of the proposed work.

The Dissertation Proposal must be defended in a public presentation, immediately followed by private questioning from the Dissertation Committee. The Dissertation Committee then determines the outcome of the Proposal Defense. It may accept the proposal, reject the proposal and recommend pursuit of a different topic, or require the student do additional work before reconsidering the proposal. The time frame for the student to do additional work on the Dissertation Proposal is determined by the Dissertation Committee.

Dissertation

All Ph.D. students must complete and orally defend a Dissertation prepared under the supervision of the Research Advisor. The research described in the Dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Dissertation must be defended in a public presentation, immediately followed by private questioning from the Dissertation Committee. The Dissertation Committee then determines the outcome of the Dissertation Defense, certifying the quality and originality of the research, and the satisfactory execution of the Dissertation. It may accept the Dissertation with or without revisions, reject the Dissertation, or require the student do additional work before reconsidering the Dissertation. The time frame for the student to complete additional work is determined by the Dissertation Committee.

Science and Technology for Innovation in Global Development

Faculty

WPI

Emmanuel Agu, Computer Science
Laureen Elgert, International Development, Environment and Sustainability*
Glenn Gaudette, Biomedical Engineering*
Robert Krueger, Social Sciences and Policy Studies, and Program Director
Geoff Pfeifer, Department of Global Studies
Anita Mattson, Chemistry and Biochemistry*
Pratap Rao, Mechanical Engineering*
Jennifer Rudolph, Humanities and Arts
Elke Rundensteiner, Data Science*
Aaron Sakulich, Civil and Environmental Engineering*
Alex Smith, Economic Sciences*
Steve Taylor, Foisie School of Business*
Yunus Telliel, Humanities and Arts
Pam Weathers, Biology and Biotechnology*
Craig Wills, Computer Science*
*Denotes faculty school/department/program liaison

Clark University

Edward Carr, International Development, Community, and Environment (IDCE)
Timothy Downs, Environmental Science, IDCE
Yelena Himmelberger, GIS and Remote Sensing, IDCE
Anthony Bebbington, Graduate School of Geography
Denise Humphreys Bebbington, International Development, IDCE
James Murphy, Graduate School of Geography
Morgan Ruelle, IDCE
Lis Gilmore, IDCE
Shadrock Roberts, IDCE

Affiliated Departments and Programs at WPI

Biomedical Engineering
Biology and Biotechnology
Chemistry and Biochemistry
Data Science Program
Economics Science Program
Foisie School of Business
Global Studies
Interactive Media and Game Development
Humanities and Arts
International Development, Environment and Sustainability Program
Social Sciences and Policy Studies

Program of Study

Master of Science in Science and Technology for Global Development

Admissions Requirements

Students applying to the Science and Technology for Innovation in Global Development program are expected to have an undergraduate degree.

M.S. in Science and Technology for Innovation in Global Development

Students pursuing the MS degree in Science and Technology for Innovation in Global Development must complete a minimum of 30 credits of relevant work at the graduate level. In some cases, students may enter the program if they have a related graduate certificate. Students may not retake courses they have already taken at WPI or elsewhere.

There are two project options satisfaction of the degree requirements. Students may take a three-credit Graduate Qualifying Project (GQP) or a six-credit MS thesis. Students will typically have a field experience no matter which track they choose. The MS degree with a GQP concentration can be completed in twelve months. The MS degree with the Thesis option will typically take one-and-a-half to two academic years. If a student seeks to add a language to their study, the program will take two years.

Upon acceptance to the MS Program, a student will be assigned to a team of academic advisors from different disciplines. In consultation with that committee the student must prepare a Plan of Study that outlines the pathway the student will take to meet the MS degree requirements.

Type: Master of Science

Core Coursework Requirement (15 Credits)

A student in the Science, Technology, and Innovation for Global Development program must take the Design Boot Camp, which begins in mid-August each year.

Item #	Title	Credits
DEV 501	Social Innovation and Global Development	3
DEV 502	Design for Social Change	3
DEV 510	Design Studio 1	3
DEV 520	Design Studio 2	3
DEV 530	Ethics and Social Justice in Science, Engineering, and Development	
DEV 540	Research Methods	

Graduate Qualifying Project / MS Thesis (3 – 6 Credits)

Item #	Title	Credits
DEV 598	Graduate Qualifying Project	3
DEV 599	Masters Thesis	3

Areas of Concentration (9-12 Credits)

A student in the Science and Technology for Innovation in Global Development program must take course work from the program electives below to satisfy the 30 required units for graduation. An elective may be any of these graduate-level courses and undergraduate courses as approved by the advisory committee and a department liaison. Students must have the prerequisite knowledge, if required, to take courses outside the program.

While design thinking for science and technology for innovation in global development is at the core of this degree requirement students may tailor their program to suit their professional needs. Course selection should provide a logical program of study. We expect that the elective courses will add depth in at least one concentration. The list of pre-approved courses follows. Other courses may be acceptable but will require approval from the advisory committee and the department liaison (when necessary).

System Dynamics

Faculty

O. V. Pavlov, Associate Professor; Ph.D., University of Southern California, 2000. Economics of information systems, political economy, system dynamics, computational economics, complex economic dynamics; opavlov@wpi.edu

M. J. Radzicki, Associate Professor; Ph.D., University of Notre Dame, 1985. Macroeconomics, monetary theory, system dynamics, predictive analytics, automated trading systems; mjradz@wpi.edu

K. Saeed, Professor; Ph.D., Massachusetts Institute of Technology, 1981. Sustainable economic development, system dynamics, organizational development, political economy, health care delivery; saeed@wpi.edu

Adjunct Faculty

K. Chichakly, Ph.D., University of Vermont, 2013. Co-President, ISEE Systems

R. Eberlein, Ph.D., Massachusetts Institute of Technology, 1984. Co-President, ISEE Systems

J. Morecroft, Ph.D., Massachusetts Institute of Technology, 1979. Senior Fellow, Management Science and Operations, London Business School

K. Warren, Ph.D. London Business School, 1995. Chairman, Global Strategy Dynamics

Program of Study

System dynamics is a dynamic computer modeling technique that is primarily used for three interrelated purposes. First, to examine the implications (costs, benefits, trade-offs, etc.) over time of competing system designs that alter the structures of complex social, physical, and/or biological systems. Second, to promote strategic thinking among model users by facilitating “single and multi-player/competitor” scenarios and “what-if” analyses. And third, to help model users reach an informed consensus on proposed changes to the structures of complex social, physical, and/or biological systems.

Although computer simulation modeling used to be an extremely technical area that was limited to specialists, modern software and hardware solutions have made it much more accessible and practical for assisting decision making at any level in or between organizations. As such, there is a strong and growing demand for graduate-level training in complex systems modeling and “systems thinking” in both the public and private sectors. To meet this demand, WPI offers a variety of graduate courses in systems modeling both online and on campus.

WPI’s system dynamics program consists of a Graduate Certificate in System Dynamics, a Master of Science in System Dynamics, and an interdisciplinary Master of Science in Systems Modeling. Students may also utilize

WPI's interdisciplinary Ph.D. framework to create a unique doctoral program that blends system dynamics modeling with another academic discipline.

B.S./M.S. in System Dynamics or System Modeling

The requirements for WPI's Master of Science in System Dynamics and Master of Science in Systems Modeling degrees are designed so that it's possible for WPI undergraduates to pursue a five-year B.S./M.S. program, in which the Bachelor's Degree is awarded in any major offered by WPI and the Master Degree is awarded in either System Dynamics or Systems Modeling.

WPI allows the double counting of up to twelve credits for students pursuing a B.S./M.S. program. This overlap can be achieved in several ways:

- Credits from up to two graduate system dynamics/ systems modeling courses may be counted toward meeting WPI's undergraduate social science requirement.
- Credits from up to four graduate system dynamics/ systems modeling courses may be counted toward meeting WPI's undergraduate mathematics/ engineering/science elective requirement, subject to the approval of the department offering the student's major.
- Credits from up to two 4000-level undergraduate courses taken in a student's major area of study may be counted toward WPI's Master Degree in System Dynamics or Systems Modeling if they can be placed in one of the categories listed in the Degree Requirements for the Master of Science in System Dynamics section or the Degree Requirements for the Master of Science in Systems Modeling section above, and are approved by the Director of WPI's Graduate Program in System Dynamics.
- Up to three graduate credits can be earned by double counting a WPI Interactive Qualifying Project or WPI Major Qualifying Project if it involves substantial use of system dynamics at an advanced level, subject to the approval of the Director of WPI's Graduate Program in System Dynamics.

Type: B.S./M.S.

Graduate Certificate Program in System Dynamics

Certificate Requirements

WPI's Graduate Certificate in System Dynamics requires fifteen credit hours of graduate study (i.e., five courses). Students must work with a faculty advisor to create a Plan of Study that consists of two foundational modeling courses and three elective courses covering methodological or application topics. A student's Plan of Study must be specified no later than the time of the completion of his or her second graduate system dynamics course.

Admission

A student will be eligible to apply for admission into WPI's Graduate Certificate in System Dynamics program if they have earned an undergraduate degree from an accredited college or university. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

Type: Certificate

M.S. in System Dynamics

The Master of Science in System Dynamics program is designed to prepare students for the professional practice of system dynamics computer simulation modeling. The curriculum is designed to provide students with an understanding of the stock-flow-feedback loop structures that cause observed patterns of behavior in complex social, physical, and/or biological systems, as well as knowledge of the use of dynamic simulation modeling for experimental analysis aimed at solving a variety of problems in the public and private sectors. This training enables students to look across disciplinary boundaries to holistically determine the desired and unintentional impacts of well-intentioned policies and technological solutions, and gives them insights into the policy implementation process in a variety of organizational settings.

Many organizations are currently supporting the training of their managers in systems thinking and system dynamics as they regard these perspectives essential for successfully navigating the modern world. Combined with an undergraduate degree in engineering, the life sciences, business, the humanities, or the social sciences, a Master Degree in System Dynamics enables a decision maker to more fully understand cross-disciplinary issues and thus contribute in innovative ways to their organization's success. WPI's Master of Science in System Dynamics may be pursued online or on campus.

Degree Requirements

WPI's Master of Science in System Dynamics requires thirty credit hours of graduate study (i.e., ten courses). At least twenty-one of these credits must be earned by taking courses in system dynamics. Students may select courses from three categories: (1) Foundational Courses (six credits), (2) Methodological Courses (nine to twelve credits), and (3) Application Courses (six to nine credits). The remaining nine credits may be earned by taking additional graduate courses in system dynamics, mathematics, organizational behavior, finance, economics, etc. Alternatively, up to six credits may be earned through project work supervised by a member of the faculty. Students must work with a faculty advisor to create a Plan of Study that must be submitted to the Director of the Graduate Program in System Dynamics during his or her first semester in the program. Students who have previously earned a Graduate Certificate in System Dynamics and wish to continue their studies to the Master level should submit their Plan of Study with their application for admission.

Admission

A student will be eligible to apply for admission into WPI's Master of Science in System Dynamics program if they have earned an undergraduate degree from an accredited college or university. Admission is also open to undergraduate students who are enrolled in WPI's five-year B.S./M.S. program, with the student's undergraduate major being determined by his or her interests. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

Type: Master of Science

M.S. in Systems Modeling

The term "systems modeling" is not limited specifically to system dynamics modeling. Indeed, other modeling techniques can also be classified under a systems heading. The curriculum embodied in WPI's Master Degree in Systems Modeling blends both system dynamics courses and more traditional mathematical modeling courses to create a broader program embodying a systems or enterprise perspective.

WPI's systems modeling curriculum involves both exact analytical, and numerical (i.e., computer simulation-based), approaches to the construction of mathematical models of complex dynamic socioeconomic, physical, or biological systems. It builds on methods native to a variety of fields such as operations research, control theory, numerical methods, and computer simulation, to establish a broad understanding of the mathematics of systems modeling, which is then applied to a plethora of domains such as management, ecology, economics, and biology. Systems modeling students study the foundations of system dynamics as well as its methodological roots in other disciplines, preparing them to mobilize the concepts they learn to solve real world problems.

Degree Requirements

WPI's Master of Science in Systems Modeling requires thirty credit hours of graduate study (i.e., ten courses). Fifteen credit hours (i.e., five courses) must be earned in the field of system dynamics and fifteen credit hours (i.e., five courses) must be earned in the area of mathematical modeling and/or an application area (e.g., industrial engineering, management, power systems, health care delivery, etc.). Up to six credits from the application area or from mathematical modeling can be earned through project work supervised by an appropriate member of the faculty. Students must work with a faculty advisor to create a Plan of Study that must be submitted to the Director of the Graduate Program in System Dynamics during his or her first semester in the program. Students who have previously earned a Graduate Certificate in System Dynamics and wish to continue their studies to the Master level should submit their Plan of Study with their application for admission.

Admission

A student will be eligible to apply for admission into WPI's Master of Science in Systems Modeling if they have earned an undergraduate degree from an accredited college or university. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

Type: Master of Science

Ph.D. in System Dynamics

WPI's Department of Social Science & Policy Studies offers an interdisciplinary Ph.D. program in system dynamics, in which students work with faculty from the Department of Social Science & Policy Studies and other WPI Ph.D.-granting departments to apply the tools and perspective of system dynamics to challenging problems in a variety of academic disciplines. Working with his or her faculty advisors, a student prepares a Plan of Study, tailored to his or her interests, that includes graduate coursework in system dynamics as well as an area of application. See page 120 for details about individually designed, interdisciplinary Ph.D. degrees.

Doctoral Committee and Plan of Study

Each Plan of Study in WPI's Interdisciplinary Ph.D. Program in System Dynamics is tailored to a student's interests, as well as to those of the participating members of the faculty. The first step in creating a Plan of Study is to assemble an interdisciplinary doctoral program committee. This committee must consist of at least three members of the faculty, with at least one member of the committee drawn from each participating department.

The Plan of Study itself is developed by the student in consultation with his or her doctoral committee. It must outline at least sixty credit hours of graduate work designed to enable the student to do original research involving the application of system dynamics to a challenging problem(s) in a particular domain. The Plan of Study should address the needs and interests of both the student and participating faculty, as well as meet all the requirements for the Ph.D.

Degree Requirements

In addition to meeting WPI's general requirements for a Ph.D., students in the Interdisciplinary Ph.D. Program in System Dynamics must complete four major steps:

1. Submit a Plan of Study approved by his or her doctoral committee to WPI's Office of the Registrar.
2. Pass a qualifying exam prior to completing eighteen credit hours (i.e., six courses) of graduate study. The purpose of this exam is to help the student's doctoral committee ascertain whether or not his or her coursework is on track, given the research agenda outlined in his or her Plan of Study.
3. Pass a dissertation proposal defense. This exam is held after a student has completed his or her course work and prepared a formal dissertation proposal. The purpose of this exam is two-fold. First, to enable the student's doctoral committee to determine whether or not the problem(s) the student has chosen for the dissertation is complex enough to warrant a Ph.D., but not so complex as to be unfinishable in a reasonable amount of time. Second, to enable the student's doctoral committee to determine whether or not the approach to solving the problem(s) the student has proposed is likely to yield new and scientifically valid results if he or she follows the approach correctly. After passing this exam a student is considered to be a Ph.D. Candidate.
4. Pass a dissertation defense. This exam is held after a student has completed his or her dissertation research. The purpose of the exam is to provide the student's doctoral committee with a chance to evaluate the final product in its entirety, as well as to enable the WPI community at large to be exposed to the original work of a new scholar.

Summary of Post-Master Degree Credits

1. Pre-Qualifying Exam Coursework: Eighteen credits (i.e., six courses)
2. Post-Qualifying Exam Coursework: A minimum of six credits (i.e., a minimum of two courses)
3. Post-Qualifying Exam/Pre-Candidacy Exam: A maximum of eighteen dissertation credits
4. Post Candidacy Exam: A minimum of twelve dissertation credits.
5. Additional Graduate Coursework or Dissertation Credits: As necessary

Note that in order to graduate a student must earn, post-Master degree, a total of at least thirty dissertation credits from numbers 3 and 4 above, and a total of at least sixty graduate credits from numbers 1-5 above.

Admission

The general admission criteria for WPI's Ph.D. programs are contained on page 9 of this Graduate Catalog. Applicants to the Interdisciplinary Ph.D. Program in System Dynamics must have earned both a bachelor degree and a Master degree from an accredited college or university and take the GRE. The GRE can be waived, however, with the approval of WPI's Graduate System Dynamics Committee.

Type: Ph.D.

System Dynamics and Innovation Management

Joint Degree Program – M.S., B.S./M.S. and Graduate Certificate

The program is designed to keep students at the forefront of business innovations by learning the essential principles and techniques of system dynamics and by applying them to critical issues in various business environments. The program prepares students to become part of the next generation of business leaders with competency in understanding internal dynamics of complex human systems so they are equipped with the knowledge, tools and skills to strategically influence decision-making in any organizational or societal setting.

Graduates of this program will be able to:

- Model a complex business decision-making situation to better understand the behavior and identify underlying influential factors so as to provide effective and sustainable innovative ideas as part of vital force of change;
- Synthesize and discern the impact of policies and technological solutions in complex systems across interdisciplinary boundaries;
- Demonstrate visionary leadership and management acumen by acquiring the technical, professional and personal knowledge to transform and/or enhance organizations.

Faculty

Khalid Saeed, Social Science and Policy Studies Department, Director of the Program
Mike Elmes, Foisie School of Business, Co-Director of the Program
All faculty in the Foisie School of Business and in the System Dynamics program are affiliated faculty for the SDIM Program.

Programs of Study

M.S., B.S./M.S. and Graduate Certificate

Admissions Requirements

For M.S. SDIM

Applicants must follow the requirements set forth for all WPI graduate applicants: https://www.wpi.edu/admissions/graduate. Specifically, a bachelor's degree is required in any discipline, along with an acceptable score on either GMAT or GRE examination. The admission decision is made based on the overall profile of an applicant. While there is no specific undergraduate major required, we believe students that will most likely succeed in the program will have had academic training and/or work experience in STEM, social science, economics, or operations research/management.

B.S./M.S. in System Dynamics and Innovation Management

Students can also pursue a B.S./M.S. degree combining any undergraduate major with M.S. in SDIM. Students enrolled in the B.S./M.S. program must satisfy all the program requirements of their B.S. degree as well as all the program requirements of the M.S. in SDIM. They may double count 4000-level courses for up to 12 credits of the 33 credit hours required for the M.S. in SDIM. They may also double count 12 credits of their graduate course credit towards meeting their undergraduate degree requirements. The conversion rate between graduate credits and undergraduate credits is stated in both the undergraduate and graduate catalogues. Thus, 18 undergraduate credits will yield 12 graduate credits and 12 graduate credits will yield 18 undergraduate credits. Minimum grade earned in double counted courses must be B. Students must register for B.S./M.S. credit prior to taking the courses, as an instructor may assign extra work for those taking a course for meeting the requirement of both degrees.

In consultation with the academic advisor, students must prepare a *Plan of Study* outlining the selections they will make to satisfy the B.S./M.S. degree requirements, including the courses that will double count. This *Plan of Study* should be submitted for approval to the SDIM Program Review Board by the end of 1st semester of enrollment into the B.S./M.S. program. Students must consult their advisors and the graduate catalog for making course selections.

Type: B.S./M.S.

Certificate in System Dynamics and Innovation Management

A graduate certificate program in SDIM is also available and requires **six** courses (18 credits) per following lists, which contain the seven SDIM required courses de- scribed above: 3 must be the required System Dynamics courses and 3 are selected from the 4 required Business courses .

Upon completion of this certificate, students will have a good understanding of how system dynamics can be applied to analyzing real-world problems and inter- pret the implications on decision-making and innovative processes.

Type: Certificate

a) Social Science and Policy Studies Department:

Item #	Title	Credits
SD 550	System Dynamics Foundation: Managing Complexity	3
SD 551	Modeling and Experimental Analysis of Complex Problems	3
SD 557	Latent Structures, Unintended Consequences, and Policy	3

Business: 3 courses selected from the following list

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
OIE 501	Operations Management	3
MIS 500	Innovating with Information Systems	3

M.S. in System Dynamics and Innovation Management

Students pursuing the M.S. SDIM program must complete a minimum of 33 credits of relevant work at the graduate level. These 33 credits must include either a 3-credit Graduate Qualifying Project or a 9-credit M.S. research thesis depending on the degree requirement option selected, in addition to the coursework requirements described below. These M.S. degree requirements are designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, as well as students who are pursuing combined B.S./M.S. degrees.

Students accepted into the program will be assigned an academic advisor. In consultation with the academic advisor, a student must prepare a Plan of Study outlining the selections that the student will make to satisfy the M.S. degree requirements from among the options offered. This Plan of Study must be submitted to the SDIM Program Review Board for approval no later than a student completes 9 credits.

Type: Master of Science

I. Required Courses (21 credits)

Students in the M.S. SDIM program must take 7 required courses: three from the Social Science & Policy Studies Department and four from the Foisie School of Business as follows:

a) Social Science and Policy Studies Department:

Item #	Title	Credits
SD 550	System Dynamics Foundation: Managing Complexity	3
SD 551	Modeling and Experimental Analysis of Complex Problems	3
SD 557	Latent Structures, Unintended Consequences, and Policy	3

b) Foisie School of Business:

Item #	Title	Credits
OBC 505	Teaming and Organizing for Innovation	3
OIE 501	Operations Management	3
MIS 500	Innovating with Information Systems	3

II. Electives (3-9 credits)

Students must take coursework from the electives listed below in order to satisfy the remainder of the 33 credit program requirement. Those opting to pursue the research thesis option will take 3 credits of electives. Those pursuing GQP option will take 9 credits of electives.

While the required courses ensure that students have adequate coverage of essential SDIM knowledge and skills, the wide variety of electives listed below allows students to tailor their degree program to domains and technical areas of personal interest. Students are expected to select electives to produce a consistent program of study. Other courses beyond the pre-approved program electives listed below may be chosen as electives with *prior* approval by the SDIM Program Review Board. Independent study and directed research credits also require *prior* approval by the SDIM Program Review Board.

Relevant System Dynamics Graduate Courses:

Item #	Title	Credits
SD 553	Model Analysis and Evaluation Techniques	3
SD 554	Real World System Dynamics	3
SD 556	Strategic Modeling and Business Dynamics	3
SD 560	Strategy Dynamics	3
SD 562	Project Dynamics	3
SD 565	Macroeconomic Dynamics	3
SD 590	Special Topics	

III. Graduate Qualifying Project (3 credits)/Thesis (9 credits)

Students in the M.S. SDIM program must complete one of the following two options:

- **A 3-credit Graduate Qualifying Project (SDIM 598)**:
  This project can be done in teams or individually, and will provide a capstone experience in applying system dynamics and innovation management skills to a real-world problem. It may be completed in cooperation with a sponsoring organization or industrial partner, and must be approved and overseen by a faculty member affiliated with the SDIM Program. Project advisor may be different from the academic advisor.

- **A 9-credit Thesis (SDIM 599)**:
  This option consists of an individual thesis research or development project. Exceptional students that wish to pursue a Ph.D. degree are encouraged to select this option. The thesis will be overseen by a committee of at least 3 faculty members chaired by a member affiliated with the SDIM program. The thesis proposal must be approved by the SDIM Program Review Board and the student's thesis committee before the student can register for the research credits. Students must satisfactorily complete a written thesis and publicly present the results.

Systems Engineering

Faculty

Faculty members hold full time positions in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

M. Amissah, Assistant Teaching Professor; Ph.D., Old Dominion University. Research focus: Model Based Systems Engineering, Systems Architecture, Complexity Science

S. Bhada, Assistant Professor, Systems Engineering; Ph.D., University of Alabama. Modeling based systems engineering (MBSE), engineering education and team mental models.

T. Gannon, Professor of Practice; Ph.D., Stevens Institute of Technology. Information systems engineering, enterprise systems engineering and integration, fault tolerant systems, information and telecommunications technology, systems architecture and design, and systems engineering capstones.

D. Gelosh, Director, Systems Engineering Programs, Ph.D., University of Pittsburgh. Advancing the overall state of

practice for systems engineering and professional development, technical leadership, defense acquisition systems, and competency models and frameworks.
J. P. Monat, Teaching Professor; Ph.D., Stanford University. Systems thinking, emergence and self-organization, system optimization, risk management, decision analysis, project management, business practices.

Programs of Study

- Master of Science in Systems Engineering
- Master of Science in Systems Engineering Leadership (program information may be found in the Interdisciplinary Programs section)
- B.S./M.S. Program in Systems Engineering
- Ph.D. in Systems Engineering
- Graduate Certificate in Systems Engineering
- Graduate Certificate in Systems Engineering Fundamentals
- Graduate Certificate in Systems Thinking
- Advanced Certificate in Systems Engineering

WPI offers graduate levels studies in the field of systems engineering leading to a Master of Science as well as graduate level certificates. These programs are designed to exemplify the WPI tradition of theory and practice and incorporate input from engineers currently practicing systems engineering. The programs integrate content from engineering, science, and management. The M.S. degree is designed to provide students with advanced knowledge of engineering systems and management supplemented with a technology focus. The degree of Doctor of Philosophy is conferred on candidates in recognition of high scientific attainments and the ability to conduct original research. Professional employment in a technological field or industry enhances the student's ability to comprehend the scope and magnitude of the complexity of systems engineering.

B.S./M.S. Program

The Master's degree in System Engineering can be earned by undergraduate students who pursue a five year Bachelor's/Master's degree program in which the Bachelor's degree is awarded in any engineering major at WPI and the Master's degree is awarded in Systems Engineering. Students who are not engineering majors but who are math or science majors and have a minor in an engineering area should contact the Systems Engineering office and discuss their plans and goals with a faculty member in the Systems Engineering program.

WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelor's-Master's Degree program. This overlap can be achieved through proper academic course planning and with the following recommendations for double counting courses.

- Students should plan to take SYS 501 in their fourth year of undergraduate studies and double count the credit toward the M.S. SE program requirement. (3 credits)
- Students should plan to take MIS 576 in their fourth year of undergraduate studies and double count the credit toward the M.S. SE program requirement. (3 credits)
- To satisfy the SE Depth Requirement, students should plan to double count any approved combination of 4000 or 500 level engineering, science or math courses that total to at least 6 graduate credits. Per WPI policy: (6 credits)
    - acceptable UG courses are awarded 2 graduate credits
    - acceptable G courses are awarded 2 or 3 graduate credits, depending on the course(s) selected.

Admitted SE B.S./M.S. program students must satisfy all of the requirements of their selected B.S. degree and all the program requirements of the SE M.S. degree. Students interested in the M.S. in Systems Engineering by electing the B.S./M.S. option are strongly encouraged to contact the Systems Engineering office for program planning help.

Admissions Requirements

Admission for the Master's degree and graduate certificates is consistent with the admission requirements listed in the Graduate Catalog for a Master of Science degree. Appropriate undergraduate bachelor's degree majors include but are not limited to Computer Science, Electrical Engineering, Mechanical Engineering, Biomedical Engineering, or Computer Engineering from an accredited university. Admission is determined by a review of the application by faculty from both the Electrical & Computer Engineering Department and the Computer Science Department.

All SE program applicants should have at least the following mathematics skills:

- An solid understanding of statistics and probability
- A strong background in general engineering mathematics and linear algebra.

Applicants who are accepted and who are judged to not have an appropriate mathematics background may be required to take a graduate level refresher course in mathematics.

Certificate in Systems Engineering

A graduate certificate provides qualified students with an opportunity to further their studies in an advanced field. Courses are selected from a range of offerings and give a firm foundation in the field of systems engineering.

Systems Thinking Certificate

This certificate program is designed to meet the needs of a variety of corporations and individuals who are interested in systems engineering education but who may have undergraduate degrees in non-engineering disciplines. The Program of Study shown below presents the requirements for the certificate. Inherent in this program of study is sufficient course selection flexibility for students to, if desired and admitted, be able to continue their graduate studies and earn an M.S. degree in Systems Engineering or SSPS/System Dynamics, depending on student interest and background. For more information consult the WPI website.

Program of Study

The Graduate Certificate in Systems Thinking is composed of 18 credits of graduate coursework, selected as follows.

- The program of study must include the following four graduate courses:
    - SYS 501 Concepts of Systems Engineering
    - SYS 540 Introduction to Systems Thinking
    - SD 550 System Dynamics Foundation: Managing Complexity
    - SD 556 Strategic Modeling and Business Dynamics
- The program of study must also include at least two additional graduate courses tailored to the interests of each student or cohort. Course can be selected from graduate courses from the School of Business, Computer Science, Engineering, Mathematics, System Dynamics and Systems Engineering. Suggested courses include the following:
- If depth in SE is desired:
    - SYS 502 Business Practices
    - SYS 512 Requirements Engineering
    - SYS 579D Engineering Dependable and Secure Systems
- If depth in SD is desired:
    - SD 501 Modeling and Experimental Analysis of Complex Problems
    - SD 562 Project Dynamics
- Additional Suggested Courses:
    - MIS 500 Innovating with Information Systems
    - •MIS 576 Project Management
    - OBC 505 Teaming and Organizing for Innovation
    - OBC 537 Leading Change
- Programs of study must be reviewed and approved by an SE or SSPS curriculum committee faculty member.

Graduate Certificate in Systems Engineering

Minimum of 17 credits. For more information, please consult the WPI web.

Graduate Certificate in Systems Engineering Fundamentals

12 credits. For more information, please consult the WPI web.

Advanced Certificate in Systems Engineering

The advanced graduate certificate in Systems Engineering consists of six courses, five in systems engineering and one elective. For more information, consult the WPI website.

Type: Certificate

M.S. in Systems Engineering Degree Requirements

The Master of Science in Systems Engineering is a ten course (30 credit-hour) degree with an emphasis on systems engineering and management supplemented with a technology focus. Table 1 lists the program degree requirements.

Type: Master of Science

Table 1: Credit distribution for the M.S. in Systems Engineering

Component	Credits
Core Requirement	12
Leadership/Management Requirement	3
Depth Requirement	6
Elective Courses	6
Capstone Experience	3
Total	**30**

Core Requirement (12 credits)

Each student must complete the core of the Systems Engineering degree program which consists of the following four 3-credit graduate systems engineering courses:

Item #	Title	Credits
SYS 501	Concepts of Systems Engineering	3
SYS 510	Systems Architecture and Design	3
SYS 511	Systems Integration, Verification and Validation	3
OIE 542	Risk Management and Decision Analysis	3

Leadership/Management Requirement (3 credits)

Systems engineers need to be aware of, and trained in, managerial methods and practices. Accordingly, each student must also complete one of the following 3-credit graduate courses:

Another leadership/management course may be substituted with the approval of the student's academic advisor.

Item #	Title	Credits
MIS 576	Project Management	3
MIS 582	Information Security Management	3
OBC 505	Teaming and Organizing for Innovation	3
OBC 506	Leadership	3
OIE 554	Global Operations Strategy	3
SD 550	System Dynamics Foundation: Managing Complexity	3
BUS 546	Managing Technological Innovation	3

Depth Requirement (6 credits, excluding capstone course requirement)

To ensure sufficient breadth of knowledge in Systems Engineering, each student must complete a minimum of 18 Systems Engineering graduate credits. In addition to the core required courses noted in the Core Requirement section, each student must complete two additional 3-credit Systems Engineering graduate courses from those listed in Table 2.

Table 2: Current Systems Engineering Graduate Courses Available to Fulfill Depth Requirement

Item #	Title	Credits
SYS 502	Business Practices	3
SYS 512	Requirements Engineering	3
SYS 520	System Optimization	3
SYS 521	Model-Based Systems Engineering	3
SYS 540	Introduction to Systems Thinking	3
SYS 579	Special Topics	3

Elective Courses (6 credits)

6 credit hours of elective graduate courses can be selected to meet the specific needs of students and organizations. All elective courses must be approved by the student's faculty advisor and can be selected from courses offered by the following departments and programs: Computer Science (CS), Systems Dynamics (SD), any WPI engineering department or program (such as ECE, BME, ME, ChE, EnvE and RBE), the School of Business, and Mathematics (MA).

Capstone Experience (3 credits minimum)

The capstone experience requirement may be satisfied by an instructor-led systems engineering project (SYS 585 Systems Engineering Capstone Experience), an individual directed research project (SYS 598 Directed Research), or a Master's Thesis (SYS 599 Thesis). The capstone experience must not exceed a total of 9 credits. Students may not transfer credit to satisfy the required capstone experience. The capstone cannot be taken until the student has successfully completed at least 24 credits, including all Core Requirements.

Ph.D. in Systems Engineering Admissions

Information regarding admissions to graduate programs in general, and Ph.D. programs in particular, is available in the Graduate Catalog (Admission Information and Application Information).

The preferred program applicant will have an M.S. in Systems Engineering. Applicants who have earned an engineering M.S. degree but not in Systems Engineering, and who have demonstrated SE work experience, will be considered for admission into the Ph.D. program based on a thorough review of their application material. Applicants possessing an M.S. in Systems Engineering from WPI are not required to submit TOEFL scores or the application fee. The Graduate Record Exam (GRE) is not required for admission, but applicants are strongly encouraged to submit GRE scores.

Acceptability of Credit Applicable to the SE Ph.D.

See graduate catalog (Acceptability of Credit).

Coursework Requirements

Students must complete 60 or more credits of graduate work beyond the credits required for the Master of Science degree. Of the 60 credits, at least 30 credits must be registered under the designation SYS 699.

The doctoral student must meet two distribution requirements for courses in areas outside of Systems Engineering. The specific courses used to meet the distribution requirements are selected in consultation with a student's Research Advisor.

For the first course distribution requirement, doctorial students must take a minimum of 12 credit hours of approved, thematically-related graduate level courses from a Science (including Computer Science), Mathematics, or Engineering program, excluding Systems Engineering. For the second course distribution requirement, doctoral students must take a minimum of 9 credit hours of approved, thematically-related graduate level courses from a Science (including Computer Science), Mathematics, or Engineering program, excluding Systems Engineering, and different from the area selected to satisfy the first course distribution requirement.

Courses which are cross-listed between the Systems Engineering program and the course offerings of another department or program cannot be used to fulfill either of these distribution requirements.

Students who enter the Systems Engineering program with a Master of Science Degree in a Science (including Computer Science), Mathematics or Engineering program, but excluding a Systems Engineering Master of Science degree, will be considered to have completed the first course distribution requirement for 12 credit hours of approved, thematically-related graduate level courses. Students who meet this exception will still be required to complete a minimum of 60 credits of graduate work, including the second course distribution requirement noted above, for the Systems Engineering Ph.D. beyond the credits required for the Master of Science degree.

All doctoral students are required to attend and pass two offerings of the SE graduate seminar courses, SYS 596A (fall semester) and SYS 596B (spring semester). Students may enroll in the graduate seminar course in any combination (e.g. two different semesters, or same semester over two years). Enrollment in the graduate seminars is required even if a student has already enrolled and counted seminar credit as part of an M.S. degree program.

Publications

All SE Ph.D. students are encouraged to submit and present their research results at appropriate academic and/or professional conferences.

Research Advisor and Dissertation Committee Selection

The doctoral student is required to select a Research Advisor or multiple Co-Advisors. In consultation with the Systems Engineering Academic Program Chair, the Research Advisor(s) form a Dissertation Committee for the student prior to scheduling the Ph.D. Qualifying Examination (described below). The following rules apply to the committee membership.

- The committee must consist of at least three faculty members if there is a single Research Advisor (or four faculty members if there are two Research Co-Advisors).
- At least one of the committee members must be a full-time, WPI tenured/tenure-track faculty member.
- At least one of the committee members and the Research Advisor (or one of the Research co-Advisors) must hold an earned doctoral degree.
- At least half of the committee members must be Systems Engineering full-time or Adjunct faculty members.
- At least one committee member must be a faculty member not affiliated with the WPI SE Program, or a recognized subject matter expert from industry.

Once the Dissertation Committee has been established, any changes to that committee must be approved by the Research Advisor(s). Changes to the student's Research Advisor(s) must be approved by the Systems Engineering Academic Program Chair. A completed Research Advisor(s) and Committee Selection form must be filed with the

Systems Engineering Program prior to taking the Qualifying Examination and each time there is a change to the Research Advisor(s) or Dissertation Committee.

Ph.D. Qualifying Examination

The doctoral student is required to successfully complete the Qualifying Examination no later than 18 credits beyond the M.S. degree. The Qualifying Examination is administered by the SE Academic Program Chair and the student's Dissertation Committee. At the discretion of the SE Academic Program Chair, additional faculty outside of the student's Dissertation Committee may also be invited to participate in the examination.

The Qualifying Examination is intended to be an opportunity to evaluate the student's level of academic preparation and identify any shortcomings in the student's background upon entrance to the Ph.D. program. The format and duration of the examination is at the discretion of the SE Academic Program Chair and Dissertation Committee. The examination may be written and/or oral and may include questions to test the general background of the student as well as questions specific to the student's intended area of research. Other formats for this examination will be acceptable if approved by the SE Academic Program Chair in consultation with the Dissertation Committee and the Research Advisor(s).

The SE Academic Program Chair and Dissertation Committee determine the outcome of the Qualifying Examination (Pass, Repeat, or Fail) and any required remediation intended to address shortcomings identified in the student's background.

- A grade of Fail will result in dismissal from the SE graduate program.
- A grade of Repeat requires the student to retake the examination within one year of the date of the initial Qualifying Examination.
- A grade of Pass is expected to also include a summary of any required remediation including, but not limited to, coursework, reading assignments, and/or independent study.
- The only permissible grades if a student takes the Qualifying Examination a second time are Pass and Fail.

Irrespective of the outcome of the examination, a Qualifying Examination Completion form, signed by the SE Academic Program Chair and Dissertation Committee members, must be filed with the Systems Engineering Program upon completion of the examination.

Upon successful completion of the Qualifying Examination, each doctoral student must submit a Ph.D. Program of Study (PoS) form with the Systems Engineering Program. The program of study should be completed in consultation with, and signed by, the student's Research Advisor(s) and should include specific course work designed to address any shortcomings identified in the student's background during the Examination.

Upon successful completion of the Ph.D. Qualifying Examination, the student becomes a SE Ph.D. candidate.

Area Examination

The doctoral student is required to pass an Area Examination prior to writing a dissertation. The Area Examination is intended to be an opportunity for the student's Research Advisor(s) and Dissertation Committee members to evaluate the suitability, scope, and novelty of the student's proposed dissertation topic. The format of the Area Examination is at the discretion of the student's Dissertation Committee but will typically include a presentation by the student describing the current state of their research field, their planned research activities, and the expected contributions of their work.

Students are eligible to take the Area Examination after they have successfully completed the Ph.D. Qualifying Examination and at least two semesters of coursework (18 graduate credit hours if part-time) in the graduate program. Failure to successfully complete the Area Examination prior to the end of the student's seventh semester (42 graduate credit hours if part-time) after Ph.D. program matriculation will be considered a failure to make satisfactory academic progress and may result in removal from the program.

The Research Advisor(s) and Dissertation Committee determine the Pass/Fail outcome of the Area Examination. A grade of Fail will result in dismissal from the SE Ph.D. graduate program. A grade of Pass may include recommendations for study or remediation. An Area Examination Completion form must be signed by the student's Research Advisor(s) and Dissertation Committee Members and filed with the Systems Engineering program Graduate Secretary upon completion of the Area examination.

Dissertation and Defense

The doctoral student must complete and orally defend publicly a dissertation prepared under the general supervision of the Research Advisor(s). The research described in the dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Research Advisor(s) and Dissertation Committee shall certify the quality and originality of the dissertation research, the satisfactory execution of the dissertation, and the preparedness of the student for the defense of the dissertation. The Graduate Secretary must be notified of a student's defense at least seven days prior to the date of the defense, without exception. The dissertation defense can be scheduled any time after the end of the semester in which the Area Examination was completed.

Residency Requirements

The student must establish residency by being a full-time graduate student for at least one continuous academic year.

Type: Ph.D.

Course Descriptions Aerospace Engineering

AE 5031: Applied Computational Methods for Partial Differential Equations
The course provides at an entry graduate level the theory and practice of finite difference and finite elements methods for partial differential equations (PDEs) encountered in fluid dynamics and solid mechanics. Topics covered include: classification of partial PDEs and characteristics; direct and iterative solution methods for solution of algebraic systems; finite difference and finite element spatial discretization; temporal discretization; consistency, stability and error analysis; explicit and implicit finite differencing and finite element schemes for linear hyperbolic, parabolic, elliptic PDEs. The course requires completion of several projects using MATLAB. Students cannot receive credit for this course if they have taken AE/ME 5108 "Computational Fluid Dynamics".
Units: 2

AE 5032: Aerospace Engineering Seminar
(0 credits) The Seminar is a degree requirement for all graduate students and is offered during A, B, C, and D term. The Seminar consists of presentations by experts on technical and broader professional topics. Presentations are also offered by graduate students on topics related to their directed research, dissertation, or industrial experiences. The Seminar is offered in pass/fail mode based on attendance.
Units: 0

AE 5093: Special Topics
Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular aerospace engineering course offerings. Exact course descriptions are disseminated by the Aerospace Engineering Program in advance of the offering.
Units: 2
Prerequisites:
Consent of instructor

AE 5098: Directed Research
These courses are offered by aerospace engineering faculty and cover diverse topics that range from 1 to 8 credits and may be completed in one or multiple terms. These courses provide M.S. and B.S./M.S. students the opportunity to gain research experience on topics of their interest. The required deliverables for successful completion of Directed Research are defined by the faculty offering the course and take into account the credits and topic involved.
Units: 0
Prerequisites:
consent of faculty offering the Directed Research

AE 5099: M.S. Thesis
Graduate students enrolled in the Master of Science thesis-option program must complete 8 credits total in AE 5099, present the results in a public forum approved by the Thesis Advisor, and submit a Master's thesis approved by the Thesis Advisor and the AED Graduate Coordinator.
Prerequisites:
enrolled in M.S. in Aerospace Engineering with Thesis option.

AE 5131: Incompressible Fluid Dynamics
This course presents topics in incompressible fluid dynamics at the introductory graduate level. Topics are chosen from: continuum fluids; kinematics and deformation for Newtonian fluids; integral and differential form of the mass conservation, momentum and energy equations; potential flows; unidirectional steady incompressible viscous flows; unidirectional transient incompressible viscous flows; boundary layers; vortical flows. Students cannot receive credit for this course if they have taken AE/ME 5101 "Fluid Dynamics" or AE/ME 5107 "Applied Fluid Dynamics."
Units: 2

AE 5132: Compressible Fluid Dynamics
This course presents applications of compressible fluid dynamics at an introductory graduate level. Topics are chosenfrom: conservation laws; propagation of disturbances; compressible flow with friction; method of characteristics,analysis and design of supersonic nozzles, diffusers, and inlets; transonic and supersonic thin-airfoil theory; three-dimensional compressible flows; compressible boundary layers; hypersonic flows; unsteady compressible flows. Students cannot receive credit for this course if they have taken AE 5093 ST: Applied Compressible Fluid Dynamics.
Units: 2

AE 5133: Kinetic Theory of Gases and Applications

The course presents kinetic theory of gases and its application to equilibrium flows and nonequilibrium flows at the introductory graduate level. Fundamental topics are chosen from: equilibrium kinetic theory; binary collisions; the Boltzmann equation; transport theory and equations. Application topics are chosen from: free molecular aerodynamics; shocks; non equilibrium flows. Students cannot receive credit for this course if they have taken AE/ME 5102"Advanced Gas Dynamics".
Units: 2

AE 5134: Plasma Dynamics

The course introduces concepts of partially ionized gases (plasmas) and their role in a wide range of science and engineering fields. Fundamental topics include: motion of charged particles in electromagnetic fields; equilibrium kinetic theory; collisions; transport theory; fluid equations; magnetohydrodynamic models; sheaths. Application topics are chosen from: plasma diagnostics; plasma discharges; spacecraft/ environment interactions, and plasma-assisted materials processing. Students cannot receive credit for this course if they have taken AE/ME 5110 "Introduction to Plasma Dynamics".
Units: 2

AE 5231: Air Breathing Propulsion

This is an introductory graduate level course that covers principles of operation, design, and performance analysis of air-breathing propulsion engines. Topics will be chosen from: jet propulsion theory; cycle analysis of turbojets, turbofans, and ram compression engines; gas dynamics of inlet and nozzle flows; thermochemistry and chemical equilibrium; combustor modeling; hypersonic propulsion; and operation of detonation engines. Students cannot receive credit for this course if they have taken AE 5106 "Air Breathing Propulsion".
Units: 2

AE 5232: Spacecraft Propulsion

This course introduces concepts needed to evaluate the performance of the most commonly used electric and chemical spacecraft propulsion systems. Fundamental topics in electric propulsion include plasma generation and ion acceleration, magnetic field design, and beam neutralization. Applications include electrostatic ion and Hall thrusters. Fundamental topics in chemical propulsion include propellant thermochemistry and ideal performance. Applications include bipropellant and monopropellant chemistry, catalyst-bed, and nozzle design considerations. Discussion of each class of thruster will be supplemented with specific examples of flight hardware. Students cannot receive credit for this course if they have taken AE/ME 5111 "Spacecraft Propulsion".
Units: 2

AE 5233: Combustion

This course introduces the principles that govern the conversion of chemical energy to thermal energy in reacting flows or combustion. Topics will be chosen from: chemical thermodynamics; chemical kinetics; transport phenomena; conservation equations; deflagrations; detonations; and diffusion flames. The course will also include discussions on energy landscape; combustion in propulsion and power generation devices; and pollutant formation. Students cannot receive credit for this course if they have taken AE5093 ST "Principles of Combustion".
Units: 2

AE 5234: Sustainable Energy Systems

The course provides an introduction to sustainable energy systems, outlining the challenges in meeting the energy needs of humanity and exploring possible solutions. Specific topics include: the current energy infrastructure;historical energy usage and future energy needs; electricity generation from the wind; ocean energy (marine hydrokinetic energy; wave energy); tethered energy systems, energy for transportation; fuel cells; solar-photovoltaic systems; geo-thermal and solar-thermal energy; energy storage; and engineering economics. Students cannot receive credit for this course if they have taken AE/ME 5105 "Renewable Energy".
Units: 2

AE 5331: Linear Control Systems

This course covers analysis and synthesis of control laws for linear dynamical systems. Fundamental concepts including canonical representations, the state transition matrix, and the properties of controllability and observability will be discussed. The existence and synthesis of stabilizing feedback control laws using pole placement and linear quadratic optimal control will be discussed. The design of Luenberger observers and Kalman filters will be introduced. Examples pertaining to aerospace engineering, such as stability analysis and augmentation of longitudinal and lateral aircraft dynamics, will be considered. Assignments and term project (if any) will focus on the design, analysis, and implementation of linear control for current engineering problems. The use of Matlab®/Simulink® for analysis and design will be emphasized. Recommended background: Familiarity with Matlab®. Students cannot receive credit for this course if they have taken AE/ME 5220 "Control of Linear Dynamical Systems".

Units: 2

AE 5332: Nonlinear Control Systems

Overview of stability concepts and examination of various methods for assessing stability such as linearization and Lyapunov methods. Introduction to various design methods based on linearization, sliding modes, adaptive control, and feedback linearization. Demonstration and performance analysis on engineering systems such as flexible robotic manipulators, mobile robots, spacecraft attitude control and aircraft control systems. Theoretical foundations of machine learning via adaptive functional estimation of dynamical systems. Control synthesis and analysis is performed using Matlab®/Simulink®. Prerequisites: Fluency with the theory of linear dynamical systems and control (AE 5331 or similar). Fluency with Matlab®. Students cannot receive credit for this course if they have taken AE/ME 5221 "Control of Nonlinear Dynamical Systems".

Units: 2

AE 5333: Optimal Control for Aerospace Applications

This course covers the synthesis of optimal control laws for linear and nonlinear dynamical systems, with a strong focus on aerospace engineering applications. Topics covered include: necessary conditions for optimal control based on the Pontryagin Minimum Principle will be introduced, and including cases of fixed and free terminal time and boundary conditions; will be discussed. Feedback optimal control will be discussed, and the Hamilton-Jacobi-Bellman equation will be introduced. The special case of linear quadratic optimal control; basic numerical techniques such as pseudospectral optimization; and modern machine learning techniques such as reinforcement learning will be discussed. Examples throughout the course will be based on air- and space vehicle applications, such as flight trajectory optimization. Assignments and term project (if any) will introduce basic numerical techniques and introduce software packages for optimal control. Prerequisites: Fluency with the theory of linear dynamical systems and control(AE 5331 or similar) and with MATLAB programming. Students cannot receive credit for this course if they have taken AE 5222 "Optimal Control".

Units: 2

AE 5334: Spacecraft Dynamics and Control

Overview of spacecraft orbital and rotational motion. Overview and sizing of actuating devices such as gas jet, electric thrusters, momentum wheels and magnetic torquers. Overview and selection of sensing devices such as sun sensors, magnetometers, GPS, IMUs. Formulation of spacecraft maneuvers as control design problems. Estimation techniques for orbit determination and attitude estimation. Static attitude determination methods. Kalman filtering for attitude estimation. Fundamentals of orbit determination. Attitude control based on Lyapunov methods. Case studies on feedback attitude regulators and algorithms for linear and nonlinear attitude tracking. Design and realization of attitude and orbital control schemes using Matlab®/Simulink®. Prerequisites: Fundamentals of spacecraft orbital motion and attitude dynamics at the undergraduate level. Fluency with the theory of linear dynamical systems and control (AE 5331 or similar) and with Matlab® programming. Students cannot receive credit for this course if they have taken AE 5223 "Space Vehicle Dynamics and Control".
Units: 2

AE 5335: Autonomous Aerial Vehicles

This course discusses the foundations of autonomy of aerial vehicles including fixed-wing aircraft and quadrotor aircraft. Topics covered include: localization using inertial sensors, GPS, and computer vision; extended Kalman filtering for localization; trajectory planning; feedback guidance for trajectory tracking; and low-level autopilot control design. Whereas this course will review aircraft dynamics, familiarity with this topic at an undergraduate level isbeneficial. Students cannot receive credit for this course if they have taken AE 5224 "Air Vehicle Dynamics and Control".
Units: 2
Prerequisites:
dynamics and control of linear systems (AE 5331 or similar); fluency with MATLAB or Python programming.

AE 5431: Solid Mechanics for Aerospace Structures

This course is an introductory graduate level course. Fundamental topics will be chosen from the following: three-dimensional states of stress; measures of strain; plane stress and plane strain; thermoelasticity; Airy stress function; and energy methods. Applied topics will be chosen from the following: bending and shear stresses on unsymmetric cross-sections; bending of composite beams; bending of curved beams; torsion of thin-walled noncircular cross sections; and failure criteria. Students cannot receive credit for this course if they have taken AE/ME 5380 "Foundations of Elasticity" or AE/ME 5381 "Applied Elasticity".
Units: 2

AE 5432: Composite Materials

This course covers the anisotropic constitutive behavior and micromechanics of composite materials, and the mechanics of composite structures at an introductory graduate level. Topics covered will be chosen from: classification of composites (reinforcements and matrices), anisotropic elasticity, composite micromechanics, effect of reinforcement on toughness and strength of composites, laminate theory, statics and buckling of laminated beams and plates, statics of laminated shells, residual stresses and thermal effects in laminates. Students cannot receive credit for this course if they have taken AE 5383 "Composite materials".
Units: 2

AE 5433: Aeroelasticity

This course provides a graduate-level introduction to static and dynamic aeroelasticity, for conventional aircraft.Students will be presented with analytical and computational techniques used to model and simulate aeroelasticity. Topics covered will be chosen from: divergence; aileron reversal; airload redistribution; sweep effects; unsteady aerodynamics; and flutter of wings. Students cannot receive credit for this course if they have taken AE/ME 5382 "Aeroelasticity".
Units: 2
Prerequisites:
AE 4712 or equivalent course.

AE 5434: Computational Solid Mechanics

This course presents finite element methods with applications to structures and structural dynamics at introductory graduate level. It focuses on linear elasticity and topics covered will be chosen from: introduction on numerical methods in solids mechanics; variational methods of approximation; formulation of finite elements and interpolation functions; assembly and solution processes; isoparametric formulation; stress recovery procedures; locking phenomenon; and dynamic problems. The course requires completion of several FEM projects and knowledge of a computer programming language.
Units: 2

AE 5435: Fracture Mechanics

This course focuses on the analytical techniques and applications of fracture mechanics at introductory graduate level. In particular, there is an emphasis on cracks in linear elastic and elasto-plastic materials encountered in high integrity aerospace structural applications. Topics covered will be chosen from: stress concentration and stress singularity near cracks, computation of stress intensity factors and asymptotic K fields, linear elastic fracture mechanics, energy methods, stability of crack propagation, cohesive fracture, basics of plasticity theory, plastic zone, small-scale yielding (SSY), HRR asymptotic fields, mixed mode fracture and elasto-plastic crack growth.
Units: 2

AE 5900: Graduate Internship Experience

(0-3 credits) A graduate internship is available for MS students in accordance to WPI rules

AE 6093: Advanced Special Topics

Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular aerospace engineering course offerings. Exact course descriptions are disseminated by the Aerospace Engineering Program in advance of the offering.
Units: 2
Prerequisites:
Consent of instructor

AE 6098: Pre-Dissertation Research

For doctoral students wishing to obtain dissertation-research credit prior to admission to candidacy.
Units: 0
Prerequisites:
Consent of dissertation advisor

AE 6099: Dissertation Research

For doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations.
Units: 0
Prerequisites:
Consent of dissertation advisor

AE 6900: Graduate Internship Experience

(0-3 credits) A graduate internship is available for Ph.D. students in accordance to WPI rules

AE 6999: Ph.D. Qualifying Examination

Admission to Candidacy will be granted when the student has satisfactorily passed the Ph.D. Qualifying Examination (AE 6999). The Qualifying Examination is intended to measure each student's fundamental knowledge in two Curricular Areas to be chosen by the student from the following: Fluid Dynamics; Propulsion and Energy; Flight Dynamics and Controls; and Materials and Structures. The AE 6999 Ph.D. Qualifying Examination is graded using a Pass/Fail system as determined by a) the results from the written Candidacy Test in the two Curricular Areas chosen by the student and b) the student's performance in graduate courses taken at WPI in the same two Curricular Areas.

The written Candidacy Test is typically offered during the first week of B and/or D term. A student will be tested on material from two (2) graduate courses of their choice in one AE Curricular Area and on material from one (1) graduate course of their choice in a second AE Curricular Area. In the term preceding the written Candidacy Test, a student must inform the Graduate Coordinator about their selection of the two Curricular Areas and the three courses. The written Candidacy Test is graded using the Satisfactory/Not Satisfactory Performance (SP/NP) grading system and has no retake.

If a student fails to register or fails to earn a Pass in the AE 6999 Ph.D. Qualifying Examination prior to completion of 18 credits after admission to the Ph.D. program, the student must withdraw from the Ph.D. program by end of the B term or D term of the year registered for the Qualifying Examination.
Units: 0

Bioinformatics and Computational Biology

BCB 501/BB 581: Bioinformatics

This course will provide an overview of bioinformatics, covering a broad selection of the most important techniques used to analyze biological sequence and expression data. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions. In addition, the course will provide students with an introduction to the theory behind some of the most important algorithms used to analyze sequence data (for example, alignment algorithms and the use of hidden Markov models). Topics covered will include protein and DNA sequence alignments, evolutionary analysis and phylogenetic trees, obtaining protein secondary structure from sequence, and analysis of gene expression including clustering methods. Students may not receive credit for both BCB 4001 and BCB 501.

Units: 3

Prerequisites:

knowledge of genetics, molecular biology, and statistics at the undergraduate level

BCB 502/CS 582: Biovisualization

This course uses interactive visualization to explore and analyze data, structures, and processes. Topics include the fundamental principles, concepts, and techniques of visualization and how visualization can be used to analyze and communicate data in domains such as biology. Students will be expected to design and implement visualizations to experiment with different visual mappings and data types, and will complete a research oriented project.

Units: 3

Prerequisites:

experience with programming (especially JavaScript), databases, and data structures. Students may not receive credit for both BCB 502 and BCB 4002.

BCB 503/CS 583: Biological and Biomedical Database Mining

This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources, including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining.

Units: 3

Prerequisites:

Strong programming skills, an undergraduate or graduate course in algorithms, an undergraduate course in statistics, and one or more undergraduate biology courses

BCB 504/MA 584: Statistical Methods in Genetics and Bioinformatics

This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees. Students may not receive credit for both BCB 4004 and BCB 504.

Units: 3

Prerequisites:

knowledge of probability and statistics at the undergraduate level

BCB 510: BCB Seminar

This seminar provides an opportunity for students in the BCB program to present their research work, as well as hear research talks from guest speakers.

Units: 0

BCB 555: Journal Club in Quantitative Cell Biology

This course is offered every other semester, discussing topics on quantitative cell biology that advance our understanding of the function of cellular systems. The focus is on reading, presenting, and discussing the most recent literature in the field. Graduate students and advanced undergraduate students with an interest in quantitative biology are encouraged to participate.
Units: 1

BCB 590: Special Topics in Bioinformatics and Computational Biology

An offering of this course will cover a topic of current interest in detail. See the Supplement section of the online catalog at www.wpi. edu/+gradcat for descriptions of courses to be offered in this academic year. Prerequisites will vary with topic.
Units: 3

BCB 596: Independent Study

This course will allow a student to study a chosen topic in Bioinformatics and Computational Biology under the guidance of a faculty member affiliated with the Bioinformatics and Computational Biology program. The student must produce a written report at the conclusion of the independent study.
Units: 3

BCB 597: Directed Research

Directed research conducted under the guidance of a faculty member affiliated with the BCB Program.
Units: 3

BCB 599: M.S. Thesis Research

A Master's thesis in Bioinformatics and Computational Biology consists of a research and development project worth a minimum of 9 graduate credit hours advised by a faculty member affiliated with the BCB Program. A thesis proposal must be approved by the BCB Program Review Board and the student's advisor before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the BCB faculty in a public presentation.
Units: 3

BCB 699: Ph.D. Dissertation Research

A Ph.D. thesis in Bioinformatics and Computational Biology consists of a research and development project worth a minimum of 30 graduate credit hours advised by a faculty member affiliated with the BCB Program. Students must pass a qualifying exam before the student can register for Ph.D. thesis credits. The student must satisfactorily complete a written dissertation, and defend it in a public presentation and a private defense.
Units: 3

BCB 5900: Graduate Internship

A graduate internship is carried out in cooperation with a sponsor or industrial partner. It must be overseen by a faculty member affiliated with the Bioinformatics and Computational Biology Program. The internship will involve development and practice of technical and professional skills and knowledge relevant to Bioinformatics and Computational Biology. At the completion of the internship, the student will produce a written report, and will present their work to BCB faculty and internship sponsors.
Units: 3

Biology and Biotechnology

BB 501: Seminar
Units: 1

BB 504: Molecular Biology of the Cell

This course will facilitate a student's functional knowledge of living cells from a biological, biochemical and technological perspective. Topics covered will include the structure, organization, growth, regulation, movements, and interaction of cells, as well as details of cellular metabolism and molecular biology. Emphasis will be placed on visualizing cellular architecture, describing the structure of DNA, describing the fate of various cellular RNAs, articulating information flow in cells, and describing protein outcomes. This course is intended to achieve a homogenous level of student understanding and can be used as a foundation course for the program. This course is designed to familiarize students with basic concepts of molecular biology including structure, organization, growth, regulation, movements, and interactions within a cell. Details of metabolism and molecular biology will be covered through projects and study of the primary literature to achieve a homogenous level of student understanding and rigor. Weekly online assessments are designed to ensure understanding. Note: Students may not receive credit for BB 504 and BB 570-196.
Units: 0

BB 505: Fermentation Biology

Material in this course focuses on biological (especially microbiological) systems by which materials and energy can be interconverted (e.g., waste products into useful chemicals or fuels). The processes are dealt with at the physiological and the system level, with emphasis on the means by which useful conversions can be harnessed in a biologically intelligent way. The laboratory focuses on measurements of microbial physiology and on bench-scale process design.

Units: 3

BB 508: Animal Cell Culture

Animal cell culture technology is about maintaining cells in vitro under controlled conditions. In recent decades this technology has advanced significantly, and animal cells are used in variety of application both in research and product development. The students in this course will be exposed to the different methodologies utilized to grow cells and how this technology is becoming critical in production of many of the health care products used to control human diseases. The course is covers four general skills (1) Basic techniques for culturing and sub-culturing animal cells and growth parameters, (2) Quality control of a cell culture laboratory/ How to control contamination, (3) Primary cell culture and development of cell lines, and (4) Scale-up of cell culture from a T-Flask to a bioreactor. Note: Students may not receive credit for BB 508 and BB 570-198

Units: 0

BB 509: Scale Up of Bioprocessing

Strategies for optimization of bioprocesses for scale-up applications will be explored. In addition to the theory of scaling up unit operations in bioprocessing, students will scale up a bench-scale bioprocess (3 liters), including fermenta- tion and downstream processing to 33 liters. Specific topics include the effects of scaling up on: mass transfer and bioreactor design, harvesting techniques including tangential flow filtration and centrifugation, and chromatography (open column and HPLC).

Units: 3

BB 515: Environmental Change: Problems and Approaches

This seminar course will examine what is known about ecological responses to both natural and human-mediated environmental changes, and explore approaches for solving ecological problems and increasing environmental sustainability. Areas of focus may include, and are not limited to, conservation genetics, ecological responses to global climate change, sustainable use of living natural resources, and the environmental impacts of agricultural biotechnology.

Units: 3

BB 551: Research Integrity in the Sciences

Students are exposed to various issues related to integrity in doing research to enable development of an appropriately reasonable course of action in order to maintain integrity on a variety of research-related performance and reporting activities. These activities include, but are not limited to data fabrication, authorship, copyright, plagiarism, unintended dual use of technology, and responsibilities towards peers who may request your confidential review or feedback. The course will use class discussion, case studies, and exercises to facilitate an understanding of the responsibilities of scientists to their profession. Students may receive credit for either BB551 or a BB570 course entitled Research Integrity in the Sciences but not both.

Units: 1

BB 552: Scientific Writing and Proposal Development

This course will cover key elements to writing successful grant proposals and manuscripts. This includes project development, identification of funding agencies or journals, proposal and manuscript writing and editing, as well as aspects of the submission and review process. Students will be expected to develop a NIH/NSF style postdoctoral proposal outside their dissertation field and participate in a mock proposal review panel. Students are expected to complete this course prior to their Qualifying Exam. Students may receive credit for either BB552 or a BB570 course entitled Scientific Writing and Proposal Development but not both.

Units: 3

BB 553: Experimental Design and Statistics in the Life Sciences

This applied course introduces students to the basics of experimental design and data analysis. Emphasis will be placed on designing biological experiments that are suitable for statistical analysis, choosing appropriate statistical tests to perform, and interpreting the results of statistical tests. We will cover statistical methods commonly used by biologists to analyze experimental data, including testing the fit of data to theoretical distributions, comparisons of groups, and regression analysis. Both parametric and non-parametric tests will be discussed. Students will use computer packages to analyze their own experimental data. Students may receive credit for either BB553 or a BB570 course entitled Experimental Design and Statistics in the Life Sciences but not both.
Units: 3

BB 554: Journal Club

This course is offered every semester covering different topics, both basic and applied, in Biology and Biotechnology and rotates among the faculty. Students read and discuss the literature in relevant topics.
Units: 1

BB 556: Mentored Teaching Experience

This course is arranged with an individual faculty member within the student's discipline. The graduate student is involved in the development of course materials, such as a syllabus, projects, or quizzes, and course delivery, such as lecturing or facilitating a conference session (20% delivery limit). In addition to covering course pedagogy, the faculty member arranges for the student teacher to be evaluated by students enrolled in the course and reviews the student reports with the student teacher.
Units: 1

BB 560: Methods of Protein Purification and Downstream Processing

This course provides a detailed hands-on survey of state-of-the-art methods employed by the biotechnology industry for the purification of products, proteins in particular, from fermentation processes. Focus is on methods that offer the best potential for scale-up. Included is the theory of the design, as well as the operation of these methods both at the laboratory scale and scaled up. It is intended for biology, biotechnology, chemical engineering and biochemistry students.
Units: 3
Prerequisites:
knowledge of basic biochemistry is assumed

BB 561: Model Systems: Experimental Approaches and Applications

The course is intended to introduce students to the use of model experimental systems in modern biological research. The course covers prokaryotic and eukaryotic systems including microbial (.Escherichia coli) and single cells eukaryotes (fungi); invertebrate (Caenorhabditis elegans, Drosophila melanogaster) and vertebrate (mice, zebra fish) systems and plants (moss, algae and Arahidopsis thaliana). Use of these systems in basic and applied research will be examined. Students may receive credit for either BB561 or a BB570 course entitled Model Systems: Experimental Approaches and Applications but not both.
Units: 2

BB 562: Cell Cycle Regulation

This course focuses on molecular events that regulate cell cycle transitions and their relevance to mammalian differentiated and undifferentiated cells. Topics include control of the Gl/S and G2/M transitions, relationships between tumor suppressor genes such as pi6, Rb, p53 or oncogenes such as cyclin D, cdc25A, MDM2 or c-myc and cell cycle control. Where appropriate, the focus is on understanding regulation of cell cycle control through transcriptional induction of gene expression, protein associations, posttranslational modifications like phosphorylation or regulation of protein stability like ubiquitin degradation. Students may receive credit for either BB562 or a BB570 course entitled Cell Cycle Regulation but not both.
Units: 3

BB 565: Virology

This advanced level course uses a seminar format based on research articles to discuss current topics related to the molecular/cell biology of viral structure, function, and evolution. Particular emphasis is placed on pathological mechanisms of various human disorders, especially emerging disease, and the use of viruses in research.
Units: 3

BB 570: Special Topics

Specialty subject courses are offered based on the expertise of the department faculty such as Stem Cell Biology.
Units: 0

BB 575: Advanced Genetics and Cellular Biology

Topics in this course focus on the basic building blocks of life: molecules, genes and cells. The course will address areas of the organization, structure, function and analysis of the genome and of cells.

Units: 3

Prerequisites:

A familiarity with fundamentals of recombinant DNA and molecular biological techniques as well as cell biology

BB 581/BCB 501: Bioinformatics

This course will provide an overview of bioinformatics, covering a broad selection of the most important techniques used to analyze biological sequence and expression data. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions. In addition, the course will provide students with an introduction to the theory behind some of the most important algorithms used to analyze sequence data (for example, alignment algorithms and the use of hidden Markov models). Topics covered will include protein and DNA sequence alignments, evolutionary analysis and phylogenetic trees, obtaining protein secondary structure from sequence, and analysis of gene expression including clustering methods. Students may not receive credit for both BB 581 and BB 4801.

Units: 3

Prerequisites:

knowledge of genetics, molecular biology, and statistics at the undergraduate level

BB 590: Capstone Experience in Biology and Biotechnology

These classes will serve as integrative experiences for graduate students who are early in their doctoral training. The course will help students integrate concepts from other courses in the curriculum, practice skills of critical analysis, and evaluate and communicate scientific information effectively. The specific theme of each offering will center around a current topic of biological interest, and may include such areas as genomics, cancer, environmental problems, and synthetic biology. Topics will be announced prior to registration in the year preceding the course offering. NOTE: Students may not earn credit for both BB 4900 and BB 590 that bear the same section number and course description.

Units: 0

BB 598: Directed Research

Directed research conducted under the guidance of a faculty member in the BB Program.

Units: 0

BB 599: Master's Thesis

A Master's thesis in Biology and Biotechnology consists of a research and development project worth a minimum of 9 graduate credit hours advised by a faculty member in the BB Program. The student must satisfactorily complete a written dissertation, public presentation, and private defense with thesis committee.

Units: 0

BB 699: Ph.D. Dissertation

A Ph.D. thesis in Biology and Biotechnology consists of a research and development project worth a minimum of 30 graduate credit hours advised by a faculty member affiliated with the BB Program. Students must pass a qualifying exam before the student can register for Ph.D. thesis credits. The student must satisfactorily complete a written dissertation, defend in a public presentation and private defense with thesis committee.

Units: 0

BCB 501/BB 581: Bioinformatics

This course will provide an overview of bioinformatics, covering a broad selection of the most important techniques used to analyze biological sequence and expression data. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions. In addition, the course will provide students with an introduction to the theory behind some of the most important algorithms used to analyze sequence data (for example, alignment algorithms and the use of hidden Markov models). Topics covered will include protein and DNA sequence alignments, evolutionary analysis and phylogenetic trees, obtaining protein secondary structure from sequence, and analysis of gene expression including clustering methods. Students may not receive credit for both BCB 4001 and BCB 501.

Units: 3

Prerequisites:

knowledge of genetics, molecular biology, and statistics at the undergraduate level

Biomedical Engineering

BME/ME 550: Tissue Engineering

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented.
Units: 3
Prerequisites:
A first course in biomaterials equivalent to BME/ME 4814 and a basic understanding of cell biology and physiology. Admission of undergraduate students requires the permission of the instructor

BME/ME 552: Tissue Mechanics

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties, and design of medical devices and prostheses.
Units: 3
Prerequisites:
An understanding of basic continuum mechanics

BME/ME 4504: Biomechanics
Units: 3

BME/ME 4606: Biofluids
Units: 3

BME/ME 4814: Biomaterials
Units: 3

BME 520/RBE 520: Biomechanics and Robotics

This course introduces Biomechanics and Robotics as a unified subject addressing living and man-made "organisms". It draws deep connections between the natural and the synthetic, showing how the same principles apply to both, starting from sensing, through control, to actuation. Those principles are illustrated in several domains, including locomotion, prosthetics, and medicine. The following topics are addressed: Biological and Artificial sensors, actuators and control, Orthotics Biomechanics and Robotics, Prosthetic Biomechanics and Robotics: Artificial Organs and Limbs, Rehabilitation Robotics and Biomechanics: Therapy, Assistance and Clinical Evaluation, Human-Robot Interaction and Robot Aided Living for Healthier Tomorrow, Sports, Exercise and Games: Biomechanics and Robotics, Robot-aided Surgery, Biologically Inspired Robotics and Micro- (bio) robotics, New Technologies and Methodologies in Medical Robotics and Biomechanics, Neural Control of Movement and Robotics Applications, Applied Musculoskeletal Models and Human Movement Analysis. This course meshes physics, biology, medicine and engineering and introduce students to subject that holds a promise to be one of the most influential innovative research directions defining the 21st century.
Units: 3
Recommended Background:
foundation of physics, linear algebra and differential equations; basic programming skills e.g. using MATLAB, undergraduate level biomechanics, robotics

BME 523: Biomedical Instrumentation

Origins and characteristics of bioelectric signals, recording electrodes, biopotential amplifiers, basic sensors, chemical, pressure, sound, and flow transducers, noninvasive monitoring techniques and electrical safety.
Units: 3
Prerequisites:
Circuits and electronics, control engineering or equivalent

BME 530/ME 5359/MTE 559: Biomedical Materials

This course is intended to serve as a general introduction to various aspects pertaining to the application of synthetic and natural materials in medicine and healthcare. This course will provide the student with a general understanding of the properties of a wide range of materials used in clinical practice. The physical and mechanical property requirements for the long term efficacy of biomaterials in the augmentation, repair, replacement or regeneration of tissues will be described. The physico-chemical interactions between the biomaterial and the physiological environment will be highlighted. The course will provide a general understanding of the application of a combination of synthetic and biological moieties to elicit a specific physiological response. Examples of the use of biomaterials in drug delivery, theranostic, orthopedic, dental, cardiovascular, ocular, wound closure and the more recent lab-on-chip applications will be outlined. This course will highlight the basic terminology used in this field and provide the background to enable the student to review the latest research in scientific journals. This course will demonstrate the interdisciplinary issues involved in biomaterials design, synthesis, evaluation and analysis, so that students may seek a job in the medical device industry or pursue research in this rapidly expanding field. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/ MTE 594) version of the same course, or for ME/BME 4814 Biomedical Materials.

Units: 2

BME 531: Biomaterials in the Design of Medical Devices

Biomaterials are an integral part of medical devices, implants, controlled drug delivery systems, and tissue engineered constructs. Extensive research efforts have been expended on understanding how biologic systems interact with biomaterials. Meanwhile, controversy has revolved around biomaterials and their availability as a result of the backlash to the huge liability resulting from controversies related to material and processing shortcomings of medical devices. This course specifically addresses the unique role of biomaterials in medical device design and the use of emerging biomaterials technology in medical devices. The need to understand design requirements of medical devices based on safety and efficacy will be addressed. Unexpected device failure can occur if testing fails to account for synergistic interactions from chronic loading, aqueous environments, and biologic interactions. Testing methodologies are readily available to assess accelerated effects of loading in physiologic-like environments. This combined with subchronic effects of animal implants is a potential tool in assessing durability. It is difficult to predict the chronic effects of the total biologic environment. The ultimate determination of safety comes not only from following the details of regulations, but with an understanding of potential failure modes and designs that lowers the risk of these failures. This course will evaluate biomaterials and their properties as related to the design and reliability of medical devices.

Units: 3

BME 532: Medical Device Regulation

This course provides an overview of regulations that guide the medical devices industry. Primary focus is on the Food, Drug and Cosmetic Act (FD&C Act) and its associated regulations. The course covers the FD&C Act, including definitions, prohibited acts, penalties and general authority. The course also covers regulations, including establishment registration, premarket approval (PMA) and current good manufacturing practices. Requirements of other federal agencies (NRC, FCC, EPA) will also be discussed.

Units: 3

BME 533/ME 5503: Medical Device Innovation and Development

The goal of this course is to introduce medical device innovation strategies, design and development processes, and provide students with an understanding of how medical device innovations are brought from concept to clinical adoption. Students will have opportunities to practice medical device innovation through a team-based course project. Specific learning outcomes include describing and applying medical device design and development concepts such as value proposition, iterative design, concurrent design and manufacturing, intellectual property, and FDA regulation; demonstrating an understanding of emerging themes that are shaping medical device innovation; demonstrating familiarity with innovation and entrepreneurship skills, including customer discovery, market analysis, development planning, and communicating innovation; and gaining capability and confidence as innovators, problem solvers, and communicators, particularly in the medical device industry but transferable to any career path.

Units: 2

BME 535: Medical Device Design Controls

An introduction to the fundamentals of medical device design controls from concept generation to manufacturing. Students work in teams to navigate through the medical device design and development lifecycle on various device types, fulfilling design control requirements while learning what is required to bring a concept to life in industry. Students may not receive credit if they previously completed this course as BME 595: Special Topics. *Does not fulfil technical depth requirement.

Units: 3

BME 553: Biomechanics of Orthopaedic Devices

This course will survey different types of orthopaedic implants and devices, primarily focusing on joint arthroplasty and fracture fixation methods. Topics such as: device design and function, mechanics, materials, validation and testing, failure, use cases, and regulatory requirements will be discussed. Class projects and discussions will cover contemporary topics related to the design, manufacture, and post-implantation measurement and performance evaluation of orthopaedic devices. Students may not receive credit if they previously completed this course as BME 595: Special Topics.

Units: 3

BME 555: Biomedical and Tissue Microengineering

This course covers microscale biological and physical phenomena and state-of-the-art techniques to measure and manipulate these processes. Topics include scaling laws, microfabrication, machining three-dimensional microstructures, patterning biomolecules, and designing and building microfluidic devices. We will cover various biomedical problems that can be addressed with microfabrication technology and their associated engineering challenges, with special emphasis on applications related to quantitative biology, tissue microengineering, controlling the cellular microenvironment, and clinical/diagnostic lab-on-a-chip devices.

Units: 3

BME 560: Physiology for Engineers

An introduction to fundamental principles in cell biology and physiology designed to provide the necessary background for advanced work in biomedical engineering. Quantitative methods of engineering and the physical sciences are stressed. Topics include cell biology, DNA technology and the physiology of major organ systems. NOTE: This course can be used to satisfy a life science requirement in the biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement.

Units: 3

BME 562: Laboratory Animal Surgery

A study of anesthesia, surgical techniques and postoperative care in small laboratory animals. Anatomy and physiology of species used included as needed. Class limited to 15 students. Approximately 15 surgical exercises are performed by each student. NOTE: This course can be used to satisfy a life science requirement in the biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement.

Units: 3

Prerequisites:

Graduate standing. Admission of undergraduate students requires the permission of the department head and the instructor.

BME 564: Cell and Molecular Biology for Engineers

An advanced course in cell and molecular biology for engineering graduate students, with an emphasis on molecular approaches to measuring and manipulating cell responses for biomedical engineering applications. Course topics will include in depth exploration of the molecular basis of cellular function, including protein biochemistry, signal transduction, cell-extracellular matrix interactions and regulation of gene expression. Tools and techniques used in modern cell and molecular biology will be discussed in the context of current research literature. NOTE: This course can be used to satisfy a life science requirement in the graduate biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement (undergraduate or graduate).

Units: 3

BME 580/RBE 580/ME 5205: Biomedical Robotics

This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussion of related literature. The course will culminate in a team project covering one or more of the primary course focus areas. Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

Units: 2

Prerequisites:

Linear algebra, ME/RBE 301 or equivalent.

BME 581: Medical Imaging Systems

Overview of the physics of medical image analysis. Topics covered include X-Ray tubes, fluoroscopic screens, image intensifiers; nuclear medicine; ultrasound; computer tomography; nuclear magnetic resonance imaging. Image quality of each modality is described mathematically, using linear systems theory (Fourier transforms, convolutions).

Units: 3

Prerequisites:

Signal analysis course BME/ECE 4011 or equivalent

BME 583: Biomedical Microscopy and Quantitative Imaging

This course introduces fundamental principles of biomedical imaging focused on quantitative microscopy. Topics include physical basis of light microscopy, fluorescence microscopy, live cell imaging and computer vision algorithms. Advanced topics include 3D imaging (confocal, light sheet, 2-photon), super-resolution, sample preparation, and equipment considerations. Selected topics in medical imaging (CT, MRI, ultrasound) may be included, with hands-on instruction on commercial and student-built systems. NOTE: Students who received credit for BME 581 in Spring 2016 may not also receive credit for BME 583.

Units: 3

BME 591: Graduate Seminar

Topics in biomedical engineering are presented both by authorities in the field and graduate students in the program. Provides a forum for the communication of current research and an opportunity for graduate students to prepare and deliver oral presentations. Students may meet the attendance requirement for this course in several ways, including attendance at weekly biomedical engineering seminars on the WPI campus, attendance at similar seminar courses at other universities or biotech firms, attendance at appropriate conferences, meetings or symposia, or in any other way deemed appropriate by the course instructor.

Units: 0

BME 592: Healthcare Systems and Clinical Practice

This course fulfills the Clinical Competency requirement in Biomedical Engineering. The course will follow a seminar format, with healthcare professionals, faculty, and medical device industry experts serving as invited lecturers and case study presenters. The course is designed to introduce BME graduate students to clinical environments and practice, healthcare delivery systems, and communication with clinical stakeholders.

Units: 1

BME 593: Scientific Communication

Clear oral, written, and graphical communication of scientific methods and data is an essential skill for success, both in research and in industry. This course will cover aspects of scientific communication including: scientific manuscript preparation and the peer review process, technical report organization, graphical presentation of quantitative data, and oral presentation of scientific information. Organization and clarity will be emphasized in communicating scientific methods, results, and interpretation. Students will complete regular writing and presentation assignments and participate in peer critique sessions. Students will complete an original research article, review article, or technical report as a final project. Students may not receive credit if they previously completed this course as BME 393: Special Topics. *Does not fulfil technical depth requirement.

Units: 3

BME 594: Biomedical Engineering Journal Club

This course will cover different topics in biomedical engineering research, both basic and translational. Enrolled students read and discuss the literature in relevant topics, which may include biomaterials, drug delivery, tissue engineering, cardiovascular engineering, mechanobiology, quantitative imaging, instrumentation, computational biomechanics, injury and rehabilitative biomechanics, or any focused topic related to biomedical engineering. The objectives of the course are for students to learn about current topics within a focused area of biomedical engineering, to improve their ability to critically review literature, and develop their technical presentation skills. Multiple sections of biomedical engineering journal club focused on different research topics may be offered each semester. Biomedical engineering graduate students may take up to 3 credits of BME 594 to satisfy Biomedical Engineering or Elective course credit to meet graduate program distribution requirements. NOTE: This course cannot be used to satisfy Biomedical Engineering or Engineering elective credit to meet undergraduate program distribution requirements.

Units: 1

Prerequisites:

Masters or Ph.D. student in biomedical engineering or a related discipline).

BME 595: Special Topics in Biomedical Engineering

Topics in biomedical engineering. Presentations and discussions of the current literature in an area of biomedical engineering.

Units: 1

BME 596: Research Seminar

Presentations on current biomedical engineering research.

Units: 3

BME 597: BME Professional Project

This course fulfills the requirement for a Project-based Master's of Science degree in Biomedical Engineering. The Professional Project is carried out in combination with an industry experience, clinical preceptorship, or design project, with oversight and input from a WPI core faculty member. Goals and objectives for the project must be documented and approved by the core faculty member, in consultation with the sponsor. To complete the project, a capstone deliverable, representative of the experience, is required. Examples of deliverables include a device prototype, public presentation, online portfolio, or another format appropriate for the specific project. Students should register for a total of 6 credits of this course, in combination with 0 credits of BME 5900 (Master's Graduate Internship Experience), BME 5910 (Master's Design Project), or BME 5920 (Master's Clinical Preceptorship).

Units: 6

BME 598: Directed Research

Students may register for Directed Research to fulfill graduate research rotation (e.g. Master's students seeking a thesis lab) or independent, mentored graduate research and projects. BME graduate students may apply up to 3 credits of BME 598 as BME course credit and an additional 3 credits of BME 598 credit to fulfill elective, laboratory rotation, or independent project credit. BME 598 credit used for laboratory rotations may be converted to BME 599 or BME 699 credit for qualified graduate students who remain in the rotation laboratory for their thesis or dissertation research.

Units: 3

Prerequisites:

Master's or Ph.D. student in biomedical engineering.

BME 599: Master's Thesis

Graduate students enrolled in the thesis-based (Master of Science, M.S.) program must complete 6 credits total and successfully defend and submit a Master's thesis by the posted deadlines.

Units: 6

Prerequisites:

Master's thesis student in biomedical engineering.

BME 698: Laboratory Rotation in Biomedical Engineering

Offered fall, spring and summer for students doing laboratory rotations on the WPI campus. Available for 3 or 4 credits.

Units: 3

Prerequisites:

Ph.D. student in biomedical engineering

BME 699: Ph.D. Dissertation

All Ph.D. students must complete 30 credits of dissertation research to fulfill Ph.D. degree requirements.

Units: 3

Prerequisites:

Student has passed the Biomedical Engineering Ph.D. Qualifying Examination.

BME 4011: Biomedical Signal Analysis

Units: 3

BME 4201: Biomedical Imaging

Units: 3

BME 4503: Computational Biomechanics

Units: 3

BME 4701: Cell and Molecular Bioengineering

Units: 3

BME 4828: Biomaterials-Tissue Interactions

Units: 3

BME 4831: Drug Delivery

Units: 3

BME 5900: Internship or Co-op

Students may apply for an industry-based co-op or internship, and earn academic credit while using elements of the co-op or internship as the basis for satisfying the project requirement.
Units: 0

BME 5910: Master's Design Project

A Masters Design Project experience is designed to enhance the professional development of the graduate student who wishes to focus on design. Masters Design Projects may be pursued within any laboratory or other organization within or external to WPI. The project deliverable must be the design or prototype of a device. This course is subject to approval by the departmental designee and sponsor.
Units: 0

BME 5920: Master's Clinical Preceptorship

A Master's Clinical Preceptorship experience is designed to enhance the professional development of the graduate student who wishes to focus on clinical applications of BME. Clinical Preceptorships may be pursued at any organization providing clinical care, such as hospitals, physician offices, dentists, and veterinary clinics. This course is subject to approval by the departmental designee and external organization.
Units: 0

BME 6999: Ph.D. Qualifying Examination

This examination is a defense of an original research proposal, made before a qualifying examination committee (QEC) representative of the areas of specialization. The examination is used to evaluate the ability of the student to pose meaningful engineering and scientific questions, to propose experimental methods for answering those questions, and to interpret the validity and significance of probably outcomes of these experiments. It is also used to test a student's comprehension and understanding of their formal coursework in life sciences, biomedical engineering and mathematics. Possible outcomes of the qualifying examination are:

1 Unconditional Pass - The candidate satisfied a majority of the QEC according to all criteria.

2. Conditional Pass with specific course work to address a specific deficiency - The candidate satisfied a majority of the QEC with the exception of a particular weakness in one of the areas of specialization. The QEC is confident that the weakness can be corrected by the candidate taking a particular course specific to the area of weakness. Upon completion of the designated course with a "B" grade or higher, the student advances to PhD candidacy.

3. Fail with an opportunity to retake within 6 months — The QEC determined that the candidate had several weaknesses. However, the majority of the QEC determined that the student has the potential to be a successful PhD candidate and could address the weaknesses. In this case, the student will have an opportunity to repeat the exam, which must be accomplished with 6 months of the original exam. The second exam only has two possible outcomes; unconditional pass, or fail without opportunity to retake the exam.

Students are required to take the Ph.D. qualifying examination no later than the fifth semester after formal admittance to the Ph.D. program. Admission to Ph.D. candidacy is officially conferred upon students who have completed their course credit requirements, exclusive of dissertation research credit, and passed the Ph.D. qualifying examination.
Units: 3

Business School, The

BUS 500: Business Law, Ethics and Social Responsibility

This course combines analysis of the structure, function and development of the law most important to the conduct of business with an examination of the ethical and social context in which managers make decisions. Emphasizing the social responsibility considerations of all business stakeholders, the course focuses on practical applications via extensive use of case studies. Students will gain a sound understanding of the basic areas of U.S. and international law including: intellectual property law; business formation and organization; international business law; securities regulation; cyber law and e-commerce; antitrust law; employment law and environmental law.
Units: 3

BUS 522: Global Business Experience

Business is increasingly global. To be successful one must understand the customs and traditions of the regions in which they are operating. This course provides students with insight into different countries and business environments and includes an international trip where students will spend a week to 10 days on the ground in the featured region meeting with business, government and/ or academic leaders; touring company sites; and learning about the region. Prior to the trip students will study business history, culture and current topics related to the featured region. Guest speakers will often be incorporated. Following the trip students will typically write reflective papers and deliver presentations.
Units: 3

BUS 545: Introduction to Health Systems

This course introduces students to the structure of health systems (suppliers, providers, and payers), exploring processes, structure, and infrastructure elements. Topics include an overview of care models and processes, health information technologies, privacy and other regulations, and payment mechanisms. The course also explores future visions of health systems, focused around wellness, patient-centeredness, and value, supported by new technologies and care models.
Units: 3

BUS 546: Managing Technological Innovation

This course studies successful innovations and how firms must enhance their ability to develop and introduce new products and processes. The course will discuss a practical model of the dynamics of industrial innovation. Cases and examples will be discussed for products in which cost and product performance are commanding factors. The important interface among R&D/ manufacturing/ marketing is discussed. International technology transfer and joint venture issues are also considered.
Units: 3

BUS 547: Energy Management

This course covers a broad spectrum of energy auditing methods, energy management planning and energy management topics important to future energy professionals, business managers and leaders. The course includes a project that applies energy management concepts to an actual energy audit. The audit project also includes the development of an energy management plan for a selected building making cost-effective recommendations to improve efficiency. Additional topics include: energy management strategies for business, governmental regulations, incentives and resources, European Union energy policies and programs including carbon credits and related markets. Energy efficiency practices as they relate to ISO 50001 Energy Management Systems, the U.S. Green Building Council (USGBC), and Leadership in Energy & Environmental Design (LEED), high performance buildings, data centers, renewable energy sources and smart grid are also studied. Special focus will be on energy management for financial and environmental sustainability benefits from the perspective of CEOs, CFOs, COOs and CSOs.
Units: 3

BUS 590: Strategic Management

This integrative and interdisciplinary course provides a broad overview of strategic management, with a focus on technology-driven organizations. Adopting a general management perspective, students will learn how to develop and execute a holistic corporate strategy that integrates key functional and business unit level strategies. Topics include data-driven strategy formulation, implementation, and evaluation. This course integrates the MBA core courses, and therefore should be taken after completing all core courses. It also serves as a prerequisite for the capstone project so it must be taken before the final capstone course (BUS 599).
Units: 3
Prerequisites:
FIN 500, MIS 584, MKT 500, OBC 506 and OIE 501 or equivalent content, or instructor consent

BUS 596: Master of Science Capstone Project

This course is the capstone course for the STEM-based, specialty MS programs in the Foisie School of Business. This course serves as a practical integration of the STEM-based tools, techniques, and skills and the related business theories and practices that students learned in their MS program. The medium is a major team-based project in the form of an actual corporate STEM-based business need for which students will develop solutions. Students will produce a written report that documents and provides the financial, organizational, and technical rationale for the solutions. They will also formally present their results to the project sponsors. Students are expected to have completed (or are currently completing) all the courses requirements for their MS program prior to taking the capstone project. While the capstone requirements are the same for all STEM-based, specialty MS programs in the Foisie School of Business, the actual content of the project will differ by sponsor and by MS program. Students must take the appropriate section of BUS 596 for each MS program they complete.

Units: 3

Prerequisites:

MIS 502, MIS 584, OBC 503, OIE 552 or equivalent content, or instructor consent

BUS 598: Independent Study

The student should have a well-developed proposal before approaching a faculty member about an independent study.

Units: 3

BUS 599: Capstone Project

This capstone course integrates management theory and practice, and incorporates a number of skills and tools acquired in the M.B.A. curriculum. The medium is a major team-based project in the form of a corporate venture or green field venture. In addition to a written report, the project is formally presented to a panel of outside experts including serial entrepreneurs and investors. (Students cannot get credit for BUS 599 and BUS 517)

Units: 3

Prerequisites:

BUS 590, FIN 500, MIS 584, MKT 500, OBC 506 and OIE 501 or equivalent content, or instructor consent

BUS 691: Graduate Seminar

Seminars on current issues related to entrepreneurship, information technology and operations management are presented by authorities in their fields. All full-time Ph.D. students in Business Administration are required to register and attend.

Units: 0

BUS 697: Independent Study

For Ph.D. students wishing to conduct independent study on special topics related to their concentration.

Units: 1

Prerequisites:

Consent of research advisor

BUS 698: Directed Research

(Credits TBD)

For Ph.D. students wishing to gain research experience peripheral to their thesis topic.

Prerequisites:

Consent of research advisor

BUS 699: Dissertation Research

Intended for Ph.D. students admitted to candidacy wishing to obtain research credit toward their dissertations.

Units: 0

Prerequisites:

Consent of research advisor

BUS 5900: Internship

The internship is an elective-credit option designed to provide an opportunity to put into practice the principles that have been studied in previous courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization, generally from off campus, and must be approved and advised by a WPI faculty member in the School of Business. Internships may be proposed by the student or by an off-campus sponsor. The internship must include proposal, design and documentation phases. Following the internship, the student will report on his or her internship activities in a mode outlined by the supervising faculty member. Students are limited to counting a maximum of 3 internship credits toward their degree requirements. Students must be making satisfactory academic progress as defined in the WPI graduate catalogue to be eligible to register for internship credit. International students who are working on a second U.S. masters degree and who have already used their master's-level Optional Practical Training (OPT) may petition the School of Business' Graduate Policy and Curriculum Committee to do additional Curricular Practical Training (CPT) beyond 3 credits on a non-credit basis. Part-time students cannot do an internship at their place of employment.

Units: 3

BUS 6900: Internship for Ph.D. Students

Units: 3

Entrepreneurship

ETR 500: Entrepreneurship and Innovation

Entrepreneurship involves many activities, including identifying and exploiting opportunities, creating and launching new ventures, introducing new products and new services to new markets. It is based on implementing innovations within existing organizations and creating new opportunities. This course is intended to introduce students to entrepreneurial thinking and methods of executing their ideas. Topics include recognizing and evaluating opportunities, forming new venture teams, preparing business and technology commercialization plans, obtaining resources, identifying execution action scenarios, and developing exit strategies.
Units: 3

ETR 593: Technology Commercialization

In the modern world of global competition the ability to utilize technological innovation is increasingly important. This course will examine the sources of new technology, the tools to evaluate new technologies, the process of intellectual property transfer, and the eventual positioning of the resultant products and services in the commercial market. Its purpose is to improve the probability of success of this discipline in both existing organizational models and early stage ventures. Specific cases studies of successful technology commercialization processes will be used to supplement the course materials.
Units: 3

ETR 596: Selling and Sales

Selling is a major part of our business and professional lives. This is especially important for those who are launching new ventures. Business propositions need to be presented to (and need to be sold to) potential investors, employees, colleagues, and certainly potential employers. Later there is a need to sell products or services to customers. Common to all is a sales process and organization model that can be developed that is focused on meeting customer and other stakeholder needs through effective selling disciplines.
Units: 3

Finance

FIN 500: Financial Management

This course develops students' financial expertise. The course focuses on financial management and corporate finance. Students learn accounting and financial concepts, principles, and methods for preparing, analyzing, and evaluating financial information, for the purpose of managing financial resources of a business enterprise and making investment decisions. Students are also introduced to the principles and methods of valuation. Students practice with the financial reporting system which enables data analysts to build queries for financial analyses and to forecast possible financial scenarios. Finally, this course focuses on financial strategy and planning to enable internal managerial decisions. Students will learn and apply budgeting techniques and manage working capital.
Units: 3

FIN 503: Financial Decision-Making for Value Creation

This course develops and enhances the student's ability to implement and clearly communicate a firm's financial decisions related to value creation. The course covers capital structure optimization, cost of capital; capital allocation and investment strategies, enterprise risk, project and firm valuation, and international financial management. The course adopts a decision-maker's perspective by emphasizing the relationships among a firm's strategic objectives, financial accounting and financial statement data, economic events, responses by market participants and other impacted constituencies, and corporate finance theory. The course also builds on these practical finance skills by incorporating team-based assignments, real-world simulations, and a variety of financial modeling tools. (Students cannot get credit for FIN 503 and FIN 500)
Units: 3

FIN 521: Financial Management in a Global Environment

This course builds from Financial Information and Management, and extends closed-economy financial management to the international market environment. Drawing from theories based on culture, corporate finance, and investor protection laws, this course examines differences in corporate governance, financial information, and financial markets in global settings. The first focus is on accountability of financial resources, the implications of globalization on firms' financial reporting and decision-making. The second focus is on international markets and institutions, how the access and exposure to different market environments can affect the firm's financial and investment decisions. Major topics include the relationship between foreign exchange and other financial variables; measurement and management of the exchange risk exposure of the firm; international investment decisions by firms and investors; and financing the global operations of firms.
Units: 3

FIN 522: Financial Institutions, Markets & Technology

This course will examine financial institutions and the relationship between U.S. capital markets and global markets. The class is intended to help students understand the impact of financial intermediaries on the global economy, businesses, and consumers. The course will investigate the organization, structure, and performance of money and capital markets and institutions. The class will examine the major financial management issues confronting financial service firms (depository institutions, insurance companies, investment banks, mutual funds, hedge funds, and pension funds), and it will address the legal, regulatory, financial reform, and risk management issues facing these financial institutions and markets. Finally, the course will address the rapid evolution of the financial sector as a result of technology. We will consider how financial technology ("FinTech") is being developed by startup technology firms and existing financial institutions may disrupt the financial sector through innovation in digital and electronic currencies, online finance and investment platforms, big data, and digital payment systems among other topics.
Units: 3

FIN 598: Special Topics
Units: 3

Management Information Systems

MIS 500: Innovating with Information Systems

This course focuses on information technology and innovation. Topics covered are information technology and organizations, information technology and individuals (privacy, ethics, job security, job changes), information technology and information security, information technology within the organization (technology introduction, and implementation, and data analytics for competitive analysis), business process engineering and information technology between organizations (electronic data interchange and electronic commerce). This course provides the knowledge and skills to utilize existing and emerging information technology innovatively to create business opportunities.
Units: 3

MIS 502: Data Management for Analytics

This course develops the skills business students need for handling data. It focuses on student skills in (1) cleaning and preparing data for analysis, (2) writing SQL queries to access and manipulate data, and (3) ethical uses of data and data privacy issues. It also covers the types of data typically found in organizations, e.g., employee, customer, product, marketing, operations, and financial data.
Units: 3

MIS 571: Database Applications Design and Development

This course introduces students to the theory and practice of computer-based data management, including the delivery of high quality data in information processing and analysis. The course focuses on the design of database systems to meet an organization's needs for data analytics. The course also covers data security, data integrity, data quality, as well as backup and recovery procedures. Students will be exposed to commercially available database management systems, such as Microsoft Access and Oracle. As a project during the course, students will design and implement a small database application that meets the data needs of some real-world business opportunity. The project report will include recommendations for ensuring data security, data integrity, and data quality.
Units: 3

MIS 573: System Design and Development

This course introduces students to the concepts and principles of systems analysis and design. It covers all aspects of the systems development life cycle from project identification through project planning and management, requirements identification and specification, process and data modeling, system architecture and security, interface design, and implementation and change management. Object-oriented analysis techniques are introduced. Students will learn to use an upper level CASE (computer-aided software engineering) tool, which will be employed in completing a real-world systems analysis and design project.
Units: 3

MIS 576: Project Management

This course presents the specific concepts, techniques and tools for managing projects effectively. The role of the project manager as team leader is examined, together with important techniques for controlling cost, schedules and performance parameters. Lectures, case studies and projects are combined to develop skills needed by project managers in todays environment.
Units: 3

MIS 581: Policy and Strategy for Information Technology and Analytics

This course focuses on the core IS capabilities that IS managers must consider when managing technology within an organization, such as IT strategy, policy development, management, and IT's role in data analytics. Fast-paced changes in technology require IT managers to quickly understand, adapt, and apply technology. Successful companies are those that can react quickly by introducing innovative technologies and respond to market demands using data driven solutions. Students will learn how IT managers engage data to develop and enhance their departments' strategies.
Units: 3

MIS 582: Information Security Management

This course introduces students to the fundamentals of Information Security Management. It is designed to develop in students an understanding of and appreciation for the importance of information security to all enterprises, and to enable current and future managers to understand the important role that they must play in securing the enterprise. This course is appropriate for any student interested in gaining a managerial-level understanding of information security. A combination of readings, lectures, case studies, guest speakers, and discussion of real world events will be used to bridge the gap between theory and practice. The course will primarily explore the Common Body of Knowledge (CBK) of information security, along with other related topics. It will also explore the interaction between People, Process and Technology as the cornerstone of any effective information security program. Upon completion of this course, the student will have an in-depth understanding of the essential components of a comprehensive information security program, as well as an understanding of the technology at work behind the scenes.
Units: 3

MIS 583: User Experience Applications

The UX Applications course provides an introduction to using UX methods to study user experience. The course teaches students how to use the newest research tools, including eye tracking and emotion detection, to study user experiences of technological products and services. Students will learn how businesses can benefit from these techniques. Both theoretical concepts and practical skills will be addressed within the scope of the class through hands-on projects, class exercises, and assignments.
Units: 3

MIS 584: Business Intelligence

This course provides students with the knowledge and skills to design, develop, and use business dashboards for monitoring organizational performance and making data-driven decisions. On the technical side, students will learn and apply business intelligence software to organize, represent, and analyze data about customers, products, sales, marketing, operations, and financials. They will learn to create strategic, operational, and analytical dashboards displaying key performance indicators (KPIs) for managerial decision-making. On the business side, students will learn the connections between business strategy and plans, the KPIs that measure performance compared to those plans, and how to use dashboards to manage organizational performance. Students will also learn the technical and managerial challenges of creating and deploying these business intelligence best practices so that organizations gain value from their data. The course includes business cases and hands-on analyses of business data. It is designed for any student interested in learning about data-driven business performance management, including students whose primary focus is Business Management, Data Science, IT, Marketing, or Operations.
Units: 3

MIS 585: User Experience Design

Designing positive user experiences is becoming increasingly important in staying competitive in the marketplace. This UX Design course offers students hands-on experiences, through the use of real-world projects, that provide them with a strong portfolio of work that showcases their skills in UX/UI, visual, service, experience, and product design. Throughout this course, students will create innovative experiences that enrich their technical fluency in both web and interactive development. The course provides a foundation in art and design in order to help students articulate their work to stakeholders and translate outcomes as business value.
Units: 3

MIS 586: User Experience Methods

In today's digital economy, understanding how people use and experience technology is crucial to designing successful technological products and services. This course covers the methodologies and tools for conducting research in the User Experience (UX) field. The course covers both qualitative and quantitative methods for conducting UX research in academia and industry, including surveys, persona development, customer journey maps, and other industry-standard tools for studying user experience. Both cutting-edge theoretical concepts and proven practical skills will be addressed within the scope of the class through hands-on projects, class exercises, and assignments.
Units: 3

MIS 587: Business Applications in Machine Learning

This course explores how Machine Learning (ML) and Artificial Intelligence (AI) is applied to solve business problems, to satisfy specific business needs, or to discover new opportunities for businesses. Applications of ML and AI are constantly evolving across many industries. This course utilizes existing AutoML solutions to address issues identified in business case studies (e.g. predicting hospital readmissions, loans likely to default, customer churn). The course covers the machine learning project life cycle starting with defining ML project objectives, acquiring and exploring data, modeling using AutoML tools, interpretation of models and communication of outcomes, and implementation and deployment of predictive models in organizations.

Units: 3

Marketing

MKT 500: Marketing Strategy

This course enables students to draw insights from data to formulate effective marketing strategies that benefit the organization and its stakeholders. Students will learn to (1) identify and understand consumers' value needs (marketing research and consumer behavior), (2) create an attractive value proposition (product and pricing strategies and tactics), and (3) communicate and deliver this value proposition (promotion and distribution strategies and tactics). Upon successful completion of this course, students will be able to develop and execute an effective data-driven marketing plan to achieve an organization's financial and marketing goals. Experiential learning techniques will be used to impart this knowledge and develop these skills.

Units: 3

MKT 561: Consumer Behavior and Analytics

We are living in a data-driven world. Everything we do from getting our news in the morning, to buying goods, and searching for information leaves trails of data across the Internet. Consumers have changed and companies need to find new ways to engage with consumers in order to stay profitable and relevant. As a working professional, you will be tasked to use data to make business decisions and develop strategy that create value for consumers and your organization. This course will introduce traditional theories of consumer behavior and then take you on a beginning journey through the dynamic practices of how to use consumer data and analytics in the digital age. Topics covered include consumer behavior theory, an examination of attitude formation and value creation, the challenges of consumer protection, market research, and the influence of technology on consumer decision making.

Units: 3

MKT 562: Marketing Research

This course is designed to equip students with research methods and tools that are used for marketing decision making. Students will learn to conduct, use, apply, interpret, and present marketing research in order to become effective decision makers. The topics covered in this course include problem formulation, research design, data collection methods, data analysis, and finally presentation of a research plan. This course will be an activity-based course involving design, implementation, and presentation of a marketing research plan. Basic knowledge of marketing and statistical concepts is assumed.

Units: 3

MKT 564: Global Technology Marketing

Extending technology to global markets requires an understanding of consumer behavior in different cultures, and effective management of risk and overseas infrastructures. This course addresses the issues associated with technology application in new markets and includes the following topics: consumer behavior differences in international markets and the implications for the marketing mix, cultural differences that affect business practices in new markets, managing exchange rate fluctuation, factors that affect manufacturing and research location, the impact of local government on marketing decision making, and the use of strategic alliances to acquire expertise and manage risk in global market development. Knowledge of marketing management is assumed.
Units: 3

MKT 565: Digital Marketing

The rapid evolution of technology has led to increasingly well-informed buyers who are connected, communicative, and more in control than ever. This course discusses the theory and practice of digital marketing and its role in building relationships and, ultimately, driving sales. It examines digital technologies and their impact on business models, the marketing mix, branding, communication strategies, and distribution channels. Emphasis is placed on contemporary topics that face todays marketing managers — including online lead generation, search, social networking, and ecommerce -and their application within a comprehensive, integrated digital marketing strategy. The course considers the opportunities and challenges faced in business-to-consumer and business-to-business markets. It covers latest research, current practices, and hands-on project work.
Units: 3

MKT 567: Integrated Marketing Communications

This course provides students with an understanding of the role of integrated marketing communications in the overall marketing program and its contribution to marketing strategy. The tools of marketing communications include advertising, sales promotion, publicity, personal selling, public relations, trade shows, direct, and online marketing. Understanding the concepts and processes that organizations use in developing effective and synergistic marketing communications is useful for managers across functional disciplines. This course will also consider ethical issues of IMC.
Units: 3

MKT 568: Data Mining Business Applications

This course provides students with the key concepts and tools to turn raw data into useful business intelligence. A broad spectrum of business situations will be considered for which the tools of classical statistics and modern data mining have proven their usefulness. Problems considered will include such standard marketing research activities as customer segmentation and customer preference as well as more recent issues in credit scoring, churn management and fraud detection. Roughly half the class time will be devoted to discussions on business situations, data mining techniques, their application and their usage. The remaining time will comprise an applications laboratory in which these concepts and techniques are used and interpreted to solve realistic business problems. Some knowledge of basic marketing principles and basic data analysis is assumed.
Units: 3

MKT 569: Product and Brand Management

The conversion of technology into new products requires an understanding of how to develop a meaningful value proposition and integrate the development of a product with a marketing strategy that creates brand equity. This course will focus on the management of products, the implications of other marketing decisions on product and brand management, the management of product lines within the organization, including introduction, growth, and market exit.
Units: 3

MKT 598: Special Topics
Units: 3

Operations and Industrial Engineering

OIE 501: Operations Management

This course focuses on the data-driven decision-making that matches supply to demand in an organization and its supply chain, emphasizing the strategic impact of operations on competitiveness and sustainability. Emergent technologies are explored as opportunities for innovation. Descriptive, predictive, and prescriptive analytical techniques are introduced to structure and evaluate key operational decisions. Skills required to model a system's operations, to address uncertainty and mitigate risk, to effectively evaluate resource needs, to integrate components into a coordinated system, and to efficiently develop and manage capacity and inventory are honed during the course.
Units: 3

OIE 542: Risk Management and Decision Analysis

Risk management deals with decision making under uncertainty. It is interdisciplinary, drawing upon management science and managerial decision-making, along with material from negotiation and cognitive psychology. Classic methods from decision analysis are first covered and then applied, from the perspective of business process improvement, to a broad set of applications in operations risk management and design including: quality assurance, supply chains, information security, fire protection engineering, environmental management, projects and new products. A course project is required (and chosen by the student according to his/her interest) to develop skills in integrating subjective and objective information in modeling and evaluating risk. (Students cannot get credit for both OIE 542 and OIE 541

Units: 3

OIE 544: Supply Chain Analysis and Design

This course studies the decisions, strategies and analytical methods in designing, analyzing, evaluating, and managing supply chains. Concepts, techniques, and frameworks for better supply chain performance are discussed, and how digital technologies enable companies to be more efficient and flexible in their internal and external operations are explored. The major content of the course is divided into three modules: supply chain integration, supply chain decisions, and supply chain management and control tools. Students will learn how to apply some of the techniques in Operations Research such as linear programming, dynamic programming, and decision tree to aid decision-making. A variety of instructional tools including lectures, case discussions, guest speakers, games, videos, and group projects and presentations are employed.

Units: 3

OIE 548: Performance Analytics

Productivity management and performance analysis techniques and applications are covered from engineering and management perspectives. Topics include benchmarking, production functions, and the concept of relative efficiency and its measurement by data envelopment analysis. Application examples include efficiency evaluations of bank branches, sales outlets, hospitals, schools and others.

Units: 3

OIE 549: Sustainable Supply Chain and Operations Management

The environmental implications and responsibilities of organizations begin at an organization's boundaries with management of their operations, but also extend to incorporate interorganizational relationships and networks, the supply chain. We will investigate the practice and theory of sustainable supply chains and operations management in organizations throughout the world. This course is intended to provide students with understanding the intra- and interorganizational implications of environmental sustainability practices and policies. The role of organizational supply chain management functions, activities, tools and methods and their relationship to the natural environment will be introduced and discussed. The goals are for students to grasp the scope of general supply chain/operations management and environmental sustainability as they relate to the firm; to be able to relate to the manners in which management may respond and collaborate internally and with suppliers, customers, and various other stakeholders influencing and influenced by operational and supply chain activities from practical and theoretical case studies; able to evaluate various factors and understand tradeoffs in management decisions as they pertain to environmental supply chain management.

Units: 3

OIE 552: Modeling and Optimizing Processes

This course is designed to provide students with a variety of quantitative tools and techniques useful in modeling, evaluating and optimizing operation processes. Students are oriented toward the creation and use of spreadsheet models to support decision-making in industry and business.
Units: 3

OIE 553: Global Purchasing and Logistics

This course aims to develop an in-depth understanding of the decisions and challenges related to the design and implementation of a firm's purchasing strategy within a context of an integrated, global supply chain. Topics centering on operational purchasing, strategic sourcing, and strategic cost management will be covered. The global logistics systems that support the purchasing process will be analyzed, and the commonly used techniques for designing and evaluating an effective logistics network will be studied.
Units: 3

OIE 554: Global Operations Strategy

This course focuses on operations strategy from a global perspective. Topics such as strategy of logistics and decisions to outsource are examined. As an example, the strategic issues concerned with firms that are doing R&D in the United States, circuit board assembly in Ireland and final assembly in Singapore. Cases, textbooks and recent articles relating to the topic are all used. Term paper based on actual cases is required.
Units: 3

OIE 556: Health Systems Modeling and Improvement

This course is organized around problem-solving frameworks for designing and improving health systems, exploring specific methodologies and their role in organizational change. Tools and techniques from operations management, industrial engineering, statistics, and management sciences, are used to explore common health systems design and management issues, focusing on data requirements and decision-making. Issues that may be explored include demand forecasting, process design, product design, and staffing and scheduling.
Units: 3

OIE 557: Service Operations Management

Successful management of service organizations often differs from that of manufacturing organizations. Service business efficiency is sometimes difficult to evaluate because it is often hard to determine the efficient amount of resources required to produce service outputs. This course introduces students to the available techniques used to evaluate operating efficiency and effectiveness in the service sector. The course covers key service business principles. Students gain an understanding of how to successfully manage service operations through a series of case studies on various service industries and covering applications in yield management, inventory control, waiting time management, project management, site selection, performance evaluation and scoring systems. The course assumes some familiarity with basic probability and statistics through regression.
Units: 3

OIE 558: Designing and Managing Lean Six Sigma Processes

In this course, Lean Six Sigma is presented as an organizational improvement system and a set of process analysis and statistical tools that have helped the world's leading organizations achieve operational excellence, saving millions of dollars and improving customer satisfaction. This course is organized in three parts: part one covers the essentials of Lean Six Sigma, including fundamental concepts and problem-solving methods; part two of the course covers Lean Six Sigma tools, including topics such as value-stream mapping, process capability, and experimental design; part three describes the major activities in a Lean Six Sigma roadmap, from identifying core processes to executing improvement projects to sustaining Lean Six Sigma gains.
Units: 3

OIE 559: Advanced Prescriptive Analytics: From Data to Impact

This course provides an in-depth focus on prescriptive analytics, which involves the use of data, assumptions, and mathematical modeling of real-world decision problems to ascertain and recommend optimal courses of action. Starting from conceptualization of the problem, to using theory for translational modeling and techniques, to computational solving, and finally interpretation – likely in an iterative manner – students will gain knowledge of tools and practical skills in transforming real-world decision problems into actionable insights. Advanced topics in the prescriptive analytics domain will be covered, such as the use of integer variables to represent important logical constructs, using nonlinear functions to represent real-world decision aspects, the incorporation of stochasticity and uncertainty, and corresponding solution methods. Real-world problems will be selected from a variety of contexts that may include capacity management, data science, finance, healthcare, humanitarian operations, inventory management, production planning, routing, staffing, and supply chain. Students will complete an individual project that includes a report in the style of a technical report or research paper, as well as an oral presentation. Students may not receive credit for both OIE 4430 and OIE 559

Units: 3

Prerequisites:

OIE 552, equivalent knowledge about optimization and linear programming, or consent of the instructor.

OIE 597: Operations and Supply Chain Consulting Project

This capstone course serves as a practical integration of the operations and supply chain theories, practices, tools and techniques that students learned in their MS program. The medium is a major team-based project, sponsored by an external organization. The course goals are: (1) to enrich students' experiential learning and support the acquisition of the skills and capabilities to tackle real-world problems; and (2) to enhance students' teamwork, interpersonal and consulting skills. Students will produce a written report documenting their solutions, and providing the financial, organizational, and technical rationale for their approach. They will also formally present their results to the project sponsors. Students are expected to have completed (or be currently completing) all the course requirements for their MS in Operations and Supply Chain Analytics prior to taking the capstone project.

Units: 3

Prerequisites:

OIE 501, OIE 544, OIE 552, OBC 505 or equivalent content, or instructor consent

OIE 598: Special Topics

Units: 3

OIE 599: Supply Chain Research

This research study is at the master's level. The course provides a research experience for students interested in studying a pressing supply chain management problem or challenge. Students must satisfactorily complete a written paper and are encouraged to publically present the results.

Units: 3

Organizational Behavior and Change

OBC 505: Teaming and Organizing for Innovation

How do we navigate complex human systems in organizations? How do we foster innovation within organizations? In this course, we explore the paradoxes, opportunities, and hidden systemic challenges that arise on teams and projects, and in working across networks and within innovative organizations. Students will learn to more deftly manage the inherent challenges and opportunities of cross-cultural and multi-disciplinary teams; work through or avoid dysfunctional team and organizational conflicts; wrestle with ambiguity and uncertainty; negotiate change by learning to work with networks of power and influence; and analyze the individual, group, organizational and contextual dynamics that enable and constrain productive and innovative work in organizations. (Students cannot get credit for OBC 505 and OBC 500)

Units: 3

OBC 506: Leadership

How do we mobilize our own and others' energy toward developing sustainable outcomes and meaningful change—when the path ahead is unclear, when our business environment is rapidly changing, when we do not have full authority over those involved? This course embraces a human-centered design approach to leading others with integrity, empathy, and curiosity—with a specific focus on the unique challenges and opportunities of working within project-based networks and Industry 4.0/STEM contexts. Students will build their capacity to navigate complex human and technical systems as they work in teams to develop and pilot a solution to a real-life organizational or social problem.
Units: 3

OBC 533: Negotiations

This course focuses on improving the student1 s understanding of the negotiation process and effectiveness as a negotiator. Emphasizes issues related to negotiating within and on behalf of organizations, the role of third parties, the sources of power within negotiation, and the impact of gender, culture and other differences. Conducted in workshop format, combining theory and practice.
Units: 3

OBC 535: Managing Creativity in Knowledge Intensive Organizations

This course considers creativity in its broadest sense from designing new products and processes to creating our own role and identity as managers and leaders in knowledge-intensive organizations. In this course we will look actively at our own creative process and how we might more fully realize our creative potential. At the same time we will build a conceptual understanding of creating, creativity, and knowledge based in the philosophic, academic, and practitioner literatures. We will critically apply this conceptual understanding to organizational examples of managing creativity in support of practical action.
Units: 3

OBC 536: Organizational Design

A key role for organizational leaders is to design their organization to achieve their desired results. This course applies design thinking and methods to the practical problems of designing various sized organizations for optimal results in a complex environment. This is based on a foundation of organizational theory, design methodology, and organizational strategy.
Units: 3

OBC 537: Leading Change

This course focuses on the role of leadership in the design and implementation of organizational change. Topics include visioning, communication, social influence, power, resiliency, and resistance to change. Teaching methods include classroom discussion of readings and cases, simulations, and experiential exercises.
Units: 3

OBC 538: Developing Managerial Talent

Assessing and developing managerial talent in yourself and others is a key to professional success and can be a source of organizational competitive advantage. This course addresses the Globalizing World and You, and provides students access to the frameworks, tools, and practice necessary to engage in thoughtful self-assessment, constructive feedback acquisition and interpretation, and strategic development planning for themselves as well as for others on their teams and in their organizations. The goals of this course are: a) to help students assess their own managerial abilities, b) to develop plans for securing new knowledge, skills and abilities that will help them in their careers, c) to set goals and agendas for their own development and d) to consider ways to translate this development process to others.
Units: 3

Chemical Engineering

CH 554/CHE 554: Molecular Modeling

This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, ab initio methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.
Units: 3

CHE 501-502: Seminar

Reports on current advances in the various branches of chemical engineering or on graduate research in progress. Must be taken during every semester in residence.
Units: 0

CHE 503: Colloquium

Presentations on scientific advances by recognized experts in various fields of chemical engineering and related disciplines. The course will be graded on a Pass/Fail basis.
Units: 0

CHE 504: Mathematical Analysis in Chemical Engineering*

An essential skill of an engineer is to provide analytical and numerical solutions to relevant problems. This course will provide students with a solid mathematical background required to solve chemical engineering problems in fields such as fluid mechanics, reactor design, thermodynamics, and process design. Methods of mathematical analysis relevant to engineering will be selected from such topics as vector analysis, matrices, eigenvalue problems, Fourier analysis, Fourier transforms, Laplace transformation, solution of ordinary and partial differential equations, integral equations, calculus of variation, optimization methods, and numerical methods. Students should have a background in undergraduate calculus and differential equations.
*Core chemical engineering courses.
Units: 3

CHE 509: Reactor Design and Kinetics*

This course includes a review of prototypical chemical reactors, including design of batch, stirred tank, and tubular reactors. Theories of reaction kinetics and catalysis for simple and complex reactions are addressed. Reactor design is discussed within the context of complex transport phenomena and reaction kinetics, including effects of bulk and pore diffusion and multiphase reactions/reactors. Techniques for experimentation, reaction data treatment, catalyst preparation and characterization, and computational tools are also included. Students cannot receive credit for this course and CHE 506 or CHE 507, which this class replaces.
*Core chemical engineering courses.
Units: 3

CHE 510: Dynamics of Particulate Systems

Analyzes discrete particles which grow in size or in some other characteristic variable (e.g., age, molecular weight). Reaction engineering and population balance analyses for batch and continuous systems. Steady state and transient system dynamics. Topics may include crystallization, latex synthesis, polymer molecular weight distribution, fermentation/ ecological systems and gas-solid systems.
Units: 3

CHE 515: Research Analysis and Design

Effective research requires understanding methods of data collection and analysis. Students will learn to apply statistical methods to analyzing data, develop mathematical models from data, visually present information, and design experiments to maximize the gain of useful information. Emphasis will also be on performing research ethically and according to accepted practices. Other topics that may be covered include: efficient use of the literature, creating and testing a hypothesis, making sound arguments, and preparing results for publication. Students should have a background in calculus. Students may not receive credit if they previously completed this course as CHE 580: Special Topics.
Units: 3

CHE 521: Biochemical Engineering
Ligand binding and membrane transport processes, growth kinetics of animal cells and micro-organisms, kinetics of interacting multiple populations, biological reactor design and analysis, soluble immobilized enzyme kinetics, optimization and control of fermentation, biopolymer structure and function, properties of biological molecules, biological separation processes, scale-up of bioprocesses; laboratory work may be included when possible.
Units: 3

CHE 531: Fuel Cell Technology
The course provides an overview of the various types of fuel cells followed by a detailed discussion of the proton-exchange membrane (PEM) fuel cell fundamentals: thermodynamics relations including cell equilibrium, standard potentials, and Nernst equation; transport and adsorption in proton-exchange membranes and supported liquid electrolytes; transport in gas-diffusion electrodes; kinetics and catalysis of electrocatalytic reactions including kinetics of elementary reactions, the Butler-Volmer equation, reaction routes and mechanisms; kinetics of overall anode and cathode reactions for hydrogen and direct methanol fuel cells; and overall design and performance characteristics of PEM fuel cells.
Units: 3

CHE 561: Thermodynamics*
Thermodynamics is at the heart of many systems of interest to chemical engineers, from the efficiency of simple mechanical processes to the equilibria of complex reactions. This course is a rigorous treatment of classical thermodynamics, with reference to the field of statistical thermodynamics. Key modules include First and Second Law analysis; behavior and interrelationships of thermodynamic properties; and fluid phase and chemical equilibria. Example topics may include analysis of open and dynamic systems; fundamental relationships; Legendre transforms and generalized potentials; Maxwell relationships; stability theory; thermodynamics of mixtures; fugacity, activity, and chemical potential; phase equilibria of systems containing two or more components; and generalized treatment of chemical equilibria. *Core chemical engineering courses.
Units: 3

CHE 565: Advanced Process Engineering
Advanced topics in process synthesis, optimization and process control are examined. Optimization topics include objective functions, multivariable optimization, constrained optimization, mixed integer linear programming and applications of optimization to process industries. Control topics include model predictive control, adaptive control, batch process control, and plant-wide control.
Units: 3
Recommended Background:
Undergraduate degree in Chemical Engineering.

CHE 571: Transport Phenomena*
Transport rates of mass, energy, and momentum are key to the design of many chemical technologies. This class adopts a unified approach to transport phenomena, providing the fundamental background required for analysis of complex problems. Students will use mathematical techniques for analytic and approximate solutions such as: separation of variables, similarity solutions, perturbation theory, and Laplace and Fourier transform methods. Methods involving non-dimensionalization and scaling will be emphasized. Special problems to be covered may include the lubrication approximation, creeping flow, and potential and laminar boundary-layer flows, as well as heat and mass transport in multi-component systems. Students are expected to have taken previous courses on transport processes and have mathematical background that includes solution of differential equations. *Core chemical engineering courses.
Units: 3

CHE 580: Special Topics
This course will focus on various topics of current interest related to faculty research experience.
Units: 3

CHE 590: Graduate Qualifying Project in Chemical Engineering

These courses provide a capstone experience in applying chemical engineering skills to real-world problems. The Graduate Qualifying Project (GQP) is carried out with an industrial partner or sponsoring agency and with the approval and oversight of a faculty member in chemical engineering. A written report and a presentation to members of the department and industrial partners are required.
Units: 3
Prerequisites:
Completion of core requirements, at least one concentration course and consent of the program director.
Recommended Background:
Undergraduate degree in Chemical Engineering, completion of the core requirements and at least one concentration course.

ME/CE 5303: Applied Finite Element Methods in Engineering

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 333 or CE 324.
Units: 2

Chemistry and Biochemistry

CH 516: Chemical Spectroscopy

The emphasis is on using a variety of spectroscopic data to arrive at molecular structures, particularly of organic molecules. Major emphasis is on inland C-NMR, IR and MS. There is relatively little emphasis on theory or on sampling handling techniques.
Units: 3

CH 520: Cell Signaling

Cell signaling defines the way cells respond to changes in their environment including, heat, nutrients, drugs, hormones, and other factors. These external factors allow cells to grow, divide, migrate and proliferate depending on the stimulus, and inappropriate responses lead to cancer and other diseases. This course is directed for advanced undergraduates and graduate level course that is a combination of on-line lectures, discussions, and review of recent literature. Students who previously took the CH 555 version of this course cannot take CH 520 for credit.
Units: 3

CH 536: Theory and Applications of NMR Spectroscopy

This course emphasizes the fundamental aspects of 1D and 2D nuclear magnetic resonance spectroscopy (NMR). The theory of pulsed Fourier transform NMR is presented through the use of vector diagrams. A conceptual nonmathematical approach is employed in discussion of NMR theory. The course is geared toward an audience which seeks an understanding of NMR theory and an appreciation of the practical applications of NMR in chemical analysis. Students are exposed to hands-on NMR operation. Detailed instructions are provided and each student is expected to carry out his or her own NMR experiments on a Bruker AVANCE 400 MHz NMR spectrometer.
Units: 3

CH 538: Medicinal Chemistry

This course will focus on the medicinal chemistry aspects of drug discovery from an industrial pharmaceutical research and development perspective. Topics will include chemotherapeutic agents (such as antibacterial, antiviral and antitumor agents) and pharmacodynamic agents (such as antihypertensive, antiallergic, antiulcer and CNS agents).
Units: 3
Prerequisites:
A good foundation in organic chemistry, e.g., CH 2310 Organic Chemistry I and CH 2320 Organic Chemistry II

CH 540: Regulation of Gene Expression

This course covers the biochemical mechanisms involved in regulation of gene expression: modifications of DNA structures that influence transcription rates, transcriptional regulation, post-transcriptional processing of RNA including splicing and editing, nuclear/cytoplasmic transport, regulation of translation, and factors that control the half-lives of both mRNA and protein. During the course, common experimental methods are explored, including a discussion of the information available from each method.

Units: 2

CH 541: Membrane Biophysics

This course will focus on different areas of biophysics with special emphasis on membrane phenomena. The biomedical-biological importance of biophysical phenomena will be stressed. The course will begin with an introduction to the molecular forces relevant in biological media and subsequently develop the following topics: membrane structure and function; channels, carriers and pumps; nerve excitation and related topics; and molecular biophysics of motility. Topics will be developed assuming a good understanding of protein and lipid chemistry, enzyme kinetics, cell biology, and electricity.

Units: 2

CH 542: Drugs in the Brain

This class will introduce the concepts of basic neuropharmacology and the action of major neurotransmitter families in the brain. The mechanisms of action of the major psychoactive drugs families including cannabis, opioids, and psychedelics will be covered. The effects of pharmaceutical treatments for anxiety and depression on brain chemistry will be discussed as well. This course will be offered in 2020-2021 and alternating years thereafter.

Units: 3

Recommended Background:
Fundamental understanding of introductory biochemistry (CH4110, CH4120, and/or CH4130).

CH 543: Organometallic Chemistry and Catalysis

Organometallic chemistry and catalytic reactions have fundamentally changed the way drugs and polymeric materials are made today. Furthermore, they have enabled the synthesis and application of new electronic materials (e.g. in OLEDs and molecular wires) and materials mimicking natural processes (e.g. self-healing and anti-bacterial coatings). This course will establish principles to understand the reactivity of organometallic compounds of transition and main groups metals. Furthermore, metal-free catalysis will be introduced. Pulling on influences from both inorganic and organic chemistry, the class will provide insight into catalysis approaches that have revolutionized synthetic chemistry, enabling highly efficient, sustainable production of compounds that are used in such different areas as drug discovery, protein analysis, and performance plastics. Case studies will be drawn from the current literature and applications that are widely used in industrial and academic settings and will include work that has led to recent Nobel prizes in the area. Recommended preparation includes the organic chemistry sequence (CH2310, CH2320, and CH2330) and CH3410. The course is recommended for both graduate and advanced undergraduate students. This course will be offered in 2018-2019 and alternate years thereafter.

Units: 3

CH 544: Elucidation of Organic Reaction Mechanisms

In this advanced course, students will develop skill sets to independently understand, explain, and predict reactions of organic molecules. Principles of modern physical organic chemistry, such as bonding, hybridization, molecular orbital theory, non-covalent interactions, stereochemistry, and conformational analysis, will be introduced alongside experimental techniques related to thermodynamics and kinetics to provide scientists with tools to understand existing reaction pathways and study new reactions. The interplay between mechanistic hypotheses and experimental observations will be demonstrated using case studies from the primary literature. Recommended for graduate students and undergraduates who have completed the sequence in organic chemistry (CH2310, CH2320, and CH2330). This course will be offered in 2019-2020 and alternating years thereafter.
Units: 3

CH 545: Plant Natural Products

This class will cover the chemistry of a number of families of plant-derived natural products, including, terpenoids, phenolic compounds, and alkaloids. The coverage of aspects of the chemistry involving these natural products may include biosynthesis, chemical synthesis, and medicinal chemistry applications. The historical and current roles of select natural products, such as tetrahydrocannabinol, taxol, heroin, and quinine, in society may also be discussed. This class will be offered in 2020-2021 and alternating years thereafter.
Units: 3
Recommended Background:
A fundamental understanding of organic chemistry, such as that obtained in an introductory organic chemistry sequence (CH2310, CH2320, and CH2330).

CH 546: Natural Product Isolation and Analysis

In this laboratory class, students will learn strategies to isolate and characterize natural products. Techniques used during this course may include solvent extraction, supercritical fluid extraction, NMR spectroscopy, IR spectroscopy, mass spectrometry, gas chromatography, and liquid chromatography. This class will be offered in 2021-2022 and alternating years thereafter.
Units: 3
Recommended Background:
Introductory chemistry laboratory experience.

CH 554/CHE 554: Molecular Modeling

This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, ab initio methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.
Units: 3

CH 555: Advanced Topics

A course of advanced study in selected areas whose content and format varies to suit the interest and needs of faculty and students. This course may be repeated for different topics covered.
Units: 1

CH 560: Current Topics in Biochemistry

In this seminar course, a different topic is selected each semester. Current articles are read and analyzed.
Units: 1

CH 561: Functional Genomics

In this seminar course, students will present and critically analyze selected, recent publications in functional genomics. The course will conclude with a written project, either a mini-grant proposal or an analysis of publicly available data in a research manuscript format. The course will be offered in alternate years in lieu of CH 360, may be repeated as many times as offered, and satisfies the departments requirement for a graduate seminar in biochemistry. This course is offered by special arrangement only, based on expressed student interest.
Units: 1

CH 571: Seminar

Reports on current advances in the various branches of chemistry.
Units: 1

CH 598: Directed Research

Units: 3

CH 599: M.S. Thesis

Units: 3

CH 699: Ph.D. Dissertation

Units: 3

CH 4110: Biochemistry I

The principles of protean structure are presented. Mechanisms of enzymatic catalysis, including those requiring coenzymes, are outlined in detail. The structures and biochemical properties of carbohydrates are reviewed. Bioenergetics, the role of ATP, and its production through glycolysis and the TCA cycle are fully considered.
Units: 3

CH 4120: Biochemistry II

Oriented around biological membranes, this term begins with a discussion of electron transport and the aerobic production of ATP, followed by a study of photosynthesis. The study of the biosynthesis of lipids and steroids leads to a discussion of the structure and function of biological membranes. Finally, the membrane processes in neurotransmission are discussed.

Units: 3

Recommended Background: CH 4110.

CH 4130: Biochemistry III

This course presents a thorough analysis of the biosynthesis of DNA (replication), RNA (transcription) and proteins (translation), and of their biochemical precursors. Proteins and RNAs have distinct lifetimes within the living cell; thus the destruction of these molecules is an important biochemical process that is also discussed. In addition to mechanistic studies, regulation of these processes is covered.

Units: 3

CH 4330: Organic Synthesis

Modern synthetic methods as applied to the construction of societally relevant target molecules will be the focus of this course. Discussions may emphasize the logic and strategy in synthetic approaches toward active pharmaceutical ingredients, agrochemicals, fine chemicals, materials, and other targets of interest. The analysis of current examples from the primary literature will draw attention to the most state-of-the-art synthetic tactics. Recommended for graduate students and undergraduates who have a basic understanding of the principles governing organic reactions, such as those covered in CH2310, CH2320, and CH2330. This course will be offered in 2018-19 and alternate years thereafter.

Units: 3

CH 4420: Inorganic Chemistry II

Complexes of the transition metals are discussed. Covered are the electronic structures of transition metal atoms and ions, and the topological and electronic structures of their complexes. Symmetry concepts are developed early in the course and used throughout to simplify treatments of electronic structure. The molecular orbital approach to bonding is emphasized. The pivotal area of organotransition metal chemistry is introduced, with focus on complexes of carbon monoxide, metal-metal interactions in clusters, and catlysis by metal complexes. This course will be offered in 2019-20 and in alternate years thereafter.

Units: 3

Recommended Background: CH 2310 and CH 2320, or equivalent.

CH 4520: Chemical Statistical Mechanics

This course deals with how the electronic, translational, rotational and vibrational energy levels of individual molecules, or of macromolecular systems are statistically related to the energy, entropy and free energy of macroscopic systems, taking into account the quantum mechanical properties of the component particles. Ensembles, partition functions, and Boltzmann, Fermi/Dirac and Bose-Einstein statistics are used. A wealth of physical chemical phenomena, including material related to solids, liquids, gases, spectroscopy and chemical reactions are made understandable by the concepts learned in this course. This course will be offered in 2019-20 and in alternate years thereafter.

Units: 3

Civil and Environmental Engineering

CE/ME 5303: Applied Finite Element Methods in Engineering

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 533 or CE 524.

Units: 2

CE 501: Professional Practice

Professional practices in engineering. Legal issues of business organizations, contracts and liability; business practice of staffing, fee structures, accounts receivable, negotiation and dispute resolution, and loss prevention; marketing and proposal development; project management involving organizing and staffing, budgeting, scheduling, performance and monitoring, and presentation of deliverables; professionalism, ethics and responsibilities.

Units: 3

CE 510: Structural Mechanics

Analysis of structural components: uniform and nonuniform torsion of structural shapes, analysis of determinate and indeterminate beams (including elastic foundation conditions) by classical methods, finite difference equations, numerical integrations, series approximation, elastic stability of beams and frames, lateral stability of beams, beams-columns, analysis of frames including the effect of axial compression.
Units: 3

CE 511: Structural Dynamics

Analysis and design of beams and frames under dynamic loads; dynamics of continuous beams, multistory building frames, floor systems and bridges; dynamic analysis and design of structures subjected to wind and earthquake loads; approximate methods of analysis and practical design applications.
Units: 3

CE 514/ME 5383: Continuum Mechanics

This course covers the fundamentals of continuum mechanics at an introductory graduate level. Topics covered include: 1) Introduction: essential mathematics - scalars, vectors, tensors, and indicial notation; 2) Basics: three-dimensional states of stress, finite and infinitesimal measures strain, and principal axes; 3) Conservations laws: mass, linear momentum, angular momentum and energy; 4) Constitutive equations: ideal materials, Newtonian fluids, isotropy and anisotropy, elasticity and thermoelasticity, plasticity, and viscoelasticity; 3) Applications to classical problems and emerging topics in solid and fluid mechanics.
Units: 2
Recommended Background:
undergraduate knowledge of strength of materials, fluid mechanics, and linear algebra.

CE 519: Advanced Structural Analysis

Energy methods in structural analysis, concepts of force method and displacement methods, methods of relaxation and numerical techniques for the solution of problems in buildings, and long-span structures and aircraft structural systems. Effects of secondary stress in structures. Course may be offered by special arrangement.
Units: 3
Prerequisites:
Structural mechanics and undergraduate courses in structural analysis, differential equations

CE 524: Finite Element Method and Applications

This course serves as an introduction to the basic theory of the finite element method. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium problem. Examples focus on elasticity and heat flow with reference to broader applications. Students are supplied microcomputer programs and gain experience in solving real problems. Note: Students cannot receive credit for both this course and CE/ME 3303 Applied Finite Element Methods.
Units: 3
Prerequisites:
Elementary differential equations, solid mechanics and heat flow.

CE 531: Advanced Design of Steel Structures

Advanced design of steel members and connections; ultimate strength design in structural steel; codes and specifications; loads and working stresses; economic proportions; and buckling of slender elements and built-up sections, torsion, lateral-torsional buckling, beam-columns, design for lateral forces, and connections for building frames.
Units: 3

CE 532: Advanced Design of Reinforced Concrete Structures

Advanced design of reinforced concrete members and structural systems; effect of continuity; codes and specifications; ultimate strength theory of design; economic proportions and constructibility considerations; and deep beams, torsion, beam-columns, two-way slabs, design for lateral forces, and beam-to-column joints.
Units: 3

CE 534: Structural Design for Fire Conditions

The development of structural analysis and design methods for steel and reinforced concrete members subjected to elevated temperatures caused by building fires. Beams, columns and rigid frames will be covered. The course is based on research conducted during the past three decades in Europe, Canada and the United States. Course may be offered by special arrangement.
Units: 3
Prerequisites:
Knowledge of statically indeterminate structural analysis, structural steel design and reinforced concrete design

CE 535: Integration of Design and Construction

As an interactive case study of the project development process, student groups design a facility and prepare a construction plan, including cost and schedule, to build the project. The students present their design-build proposal to participating industrial clients. Emphasis is on developing skills to generate, evaluate and select design alternatives that satisfy the needs of the owner and the constraints imposed by codes and regulations, as well as by the availability of construction resources. Emphasis is also in developing team-building skills and efficient communication. Computer-based methods for design, construction cost estimating and scheduling, and personal communications are extensively used. The interactive case study is specifically chosen to balance the content between design, construction engineering and management. Students taking this course are expected to have a background in at least two of these disciplines.
Units: 3

CE 536: Construction Failures: Analysis and Lessons

This course develops an understanding of the integration process of technical, human, capital, social and institutional aspects that drive the life cycle of a construction project. The study of failures provides an excellent vehicle to find ways for the improvement of planning, design and construction of facilities. Student groups are required to complete a term project on the investigation of a failure and present their findings and recommendations. This investigation includes not only the technical analysis of the failure but also requires a comprehensive analysis of the organizational, contractual and regulatory aspects of the process that lead to the failure. The course uses case studies to illustrate different types of failure in the planning, design, construction and operation of constructed facilities. Students taking this course are expected to have a sound academic or practical background in the disciplines mentioned above.
Units: 3

CE 538: Pavement Analysis and Design for Highways and Airports

This course is designed for civil engineers and provides a detailed survey of analysis and design concepts for flexible and rigid pavements for highways and airports. The material covers elastic and inelastic theories of stress pavement components and currently used design methods, i.e., Corps of Engineers, AASHTO, etc. The use of finite element methods for pavement stress and deformation analysis are presented. A review of pavement rehabilitation methods and processes is presented.
Units: 3
Prerequisites:
differential equations, construction materials, soil mechanics, computer literacy

CE 542: Geohydrology

This course addresses engineering problems associated with the migration and use of subsurface water. An emphasis is placed on the geology of water-bearing formations including the study of pertinent physical and chemical characteristics of soil and rock aquifers. Topics include principles of groundwater movement, geology of groundwater occurrence, regional groundwater flow, subsurface characterization, water well technologies, groundwater chemistry and unsaturated flow.
Units: 3

CE 560: Advanced Principles of Water Treatment

Theory and practice of drinking water treatment. Water quality and regulations; physical and chemical unit processes including disinfection, coagulation, clarification, filtration, membranes, air stripping, adsorption, softening, corrosion control, and other advanced processes.
Units: 3

CE 561: Advanced Principles of Wastewater Treatment

Theory and practice of wastewater treatment. Natural purification of streams; screening; sedimentation; flotation, thickening; aerobic treatment methods; theory of aeration; anaerobic digestion; disposal methods of sludge including vacuum filtration, centrifugation and drying beds; wet oxidation; removal of phosphate and nitrogen compounds; and tertiary treatment methods.
Units: 3

CE 562: Biosystems in Environmental Engineering

Application of microbial and biochemical understanding to river and lake pollution; natural purification processes; biological conversion of important elements such as C, N, S, O and P; biological aspects of wastewater treatment; disease-producing organisms with emphasis on waterborne diseases; and quantitative methods used in indicator organism counts and disinfection.
Units: 3

CE 563: Industrial Waste Treatment

Legislation; the magnitude of industrial wastes; effects on streams, sewers and treatment units; physical, chemical and biological characteristics; pretreatment methods; physical treatment methods; chemical treatment methods; biological treatment methods; and wastes from specific industries. Lab includes characterization and treatment of typical industrial wastes.
Units: 3

CE 565: Surface Water Quality Modeling

This course provides a quantitative analysis of the fate and transport of contaminants in surface water systems. Water quality models are developed using a mass balance approach to describe the transport, dispersal, and chemical/biological reactions of substances introduced into river and lake systems. Topics covered include water quality standards, model formulation and application, waste load allocation, and water quality parameters such as biochemical oxygen demand, dissolved oxygen, nutrients, and toxic chemicals.
Units: 3

CE 566: Groundwater Flow and Pollution

This course provides a review of the basic principles governing ground water flow and solute transport, and examines the models available for prediction and analysis including computer models. Topics covered include mechanics of flow in porous media; development of the equations of motion and of conservation of solute mass; analytical solutions; and computer-based numerical approaches and application to seepage, well analysis, artificial recharge, groundwater pollution, salinity intrusion and regional groundwater analyses.
Units: 3

CE 567: Hazardous Waste: Containment, Treatment and Prevention

This course provides a survey of the areas associated with hazardous waste management. The course materials deal with identification of hazardous waste legislation, containment, storage, transport, treatment and other hazardous wastes management issues. Topics include hazardous movement and containment strategies, barrier design considerations, hazardous waste risk assessment, spill response and clean-up technologies, centralized treatment facilities, onsite treatment, in situ treatment, and industrial management and control measures. Design of selected containment and treatment systems, and a number of industrial case studies are also covered. This course is offered to students with varying backgrounds. Students interested in taking this course must identify a specific problem that deals with either regulation, containment of hazardous waste, treatment of hazardous waste or industrial source reduction of hazardous waste. This problem becomes the focal point for in-depth study. The arrangement of topics between the students and the instructor must be established by the third week. A knowledge of basic chemistry is assumed.
Units: 3

CE 570: Contaminant Fate and Transport

This course introduces the concepts of contaminant fate and transport processes in the environment, with consideration to exchanges across phase boundaries and the effects of reactions on environmental transport. Topics include equilibrium conditions at environmental interfaces, partitioning and distribution of contaminants in the environment, transport and exchange processes in surface water; dispersion, sorption, and the movement of non-aqueous phase liquids in ground-water, and local, urban and regional scale transport processes in the atmosphere.
Units: 3

CE 571: Water Chemistry

This course covers the topics of chemical equilibrium, acid/base chemistry, the carbonate system, solubility of metals, complexation and oxidation-reduction reactions. These principles will be applied to understanding of the chemistry of surface waters and groundwaters, and to understanding the behavior of chemical processes used in water and wastewater treatment.
Units: 3

CE 572: Physical and Chemical Treatment Processes

This course presents the physical and chemical principles for the treatment of dissolved and particulate contaminants in water and wastewater. These concepts will provide an understanding of the design of commonly used unit operations in treatment systems. Applications will be discussed as well. Topics covered include water characteristics, reactor dynamics, filtration, coagulation/flocculation, sedimentation, adsorption, gas stripping, disinfection, and chemical oxidation.
Units: 3

CE 573: Treatment System Hydraulics

Hydraulic principles of water, domestic wastewater and industrial wastewater systems. Hydraulic analysis and design of collection, distribution and treatment systems and equipment. Topics covered include pipe and channel flow, pump characteristics and selection, friction loss, corrosion and material selection.
Units: 3

CE 574: Water Resources Management

This course provides an introduction to water resources engineering and management, with an emphasis on water resources protection and water supply. Course content addresses technical aspects as well as the legal, regulatory and policy aspects of water resources management. Topics include surface water hydrology and watershed protection, development of water supplies, conjunctive use of groundwater and surface water, management of reservoirs and rivers, the role of probability and statistics, systems analysis techniques, and planning of water resources projects.
Units: 3

CE 575: Climate and the Earth System

This course deals with the Earth's operation as a system, covering its energy budget along with its interacting atmosphere, ocean, biosphere and geologic systems. By showing how all systems work together to form feedback loops that can amplify or counteract input perturbations and forcings of the overall system, the course illustrates how these systems modulate and control our planet's climate system. Throughout, an Anthropocene point of view is taken to study not only "natural" systems but also the ways in which human societies interact with and are an integral part of the Earth system. The course integrates physical, chemical, and biological basics to arrive at an understanding of complex natural and human systems.
Units: 2

CE 580: Advanced Project Management

This course develops an understanding of the managerial principles and techniques used throughout a construction project as they are applied to its planning, preconstruction and construction phases. The course emphasizes the integrative challenges of the human, physical and capital resources as experienced from the owner's point of view in the preconstruction phase of a project. Through assignments and case studies, the course reviews the complex environment of the construction industry and processes, project costing and economic evaluation, project organization, value engineering, time scheduling, contracting and risk allocation alternatives, contract administration, and cost and time control techniques.
Units: 3
Prerequisites:
CE 3020, CE 3023, or equivalent

CE 582: Engineering and Construction Information Systems

This course provides an understanding of the various subjects involved in the use, design, development, implementation and maintenance of computer- based information systems in the construction industry. Theoretical and hands-on review of basic building blocks of information and decision support systems including user interfaces, database management systems, object-oriented approaches and multimedia. Applications include project scheduling and cost control, budgeting, project risk analysis, construction accounting, materials management and procurement systems, project document tracking and resource management. Commercial software—such as PRIMAVERA Project Planner, TIMBERLINE, and spreadsheets and databases—is extensively used. Students are required to complete a term project reviewing an existing information system and presenting recommendations for improvement. Course may be offered by special arrangement.
Units: 3
Prerequisites:
A knowledge of the material covered in CE 380 and CE 584 is expected.

CE 583: Contracts and Law for Civil Engineers

An introduction to the legal aspects of construction project management, emphasis on legal problems directly applied to the practice of project management, contracts and specifications documents, codes and zoning laws, and labor laws.
Units: 3

CE 584: Advanced Cost Estimating Procedures

This course examines cost estimating as a key process in planning, designing and constructing buildings. Topics include the analysis of the elements of cost estimating; database development and management, productivity, unit costs, quantity surveys and pricing, and the application of these tools in business situations; marketing, sales, bidding, negotiating, value engineering, cost control, claims management and cost history. Computerization is evaluated as an enhancement to the process.
Units: 3

CE 586: Building Systems

This course introduces design concepts, components, materials and processes for major building projects. The topics analyze the choice of foundations, structures, building enclosures and other major building subsystems as affected by environmental and legal conditions, and market and project constraints. Consideration is given to the functional and physical interfaces among building subsystems. Emphasis is given to the processes through which design decisions are made in the evolution of a building project.
Units: 3

CE 587: Building Information Modeling (BIM)

This course introduces the concept of Building Information Modeling (BIM) which is a relatively new approach in planning, design, construction and operation of constructed facilities in a technologically enabled and collaborative fashion. The course reviews fundamental concepts for collaboration and integration; it also reviews technologies that support the BIM approach and provides discipline specific as well as global perspectives on BIM. The course format includes formal lectures, computer laboratory sessions, student presentations based on assigned readings and a project developed collaboratively by the students throughout the course. Guest speakers may be invited based on the topics covered and discussed in class. Students are not permitted to receive credit for CE 587 if they have previously received credit for CE 585 or CE 590A-BIM.
Units: 3
Prerequisites:
Basic knowledge of computers. Exposure to professional practice in any area of the Architecture/ Engineering/ Construction/ Facilities Management (A/E/C/FM) industry is desirable.

CE 590: Special Problems

Individual investigations or studies of any phase of civil engineering as may be selected by the student and approved by the faculty member who supervises the work.
Units: 2

CE 591: Environmental Engineering Seminar

Participation of students in discussing topics of interest to environmental engineers.
Units: 3

CE 592: Constructed Facilities Seminar

Participation of students, faculty and recognized experts outside of WPI in developing modern and advanced topics of interest in the constructed facilities area.

Units: 3

CE 593: Advanced Project

This capstone project is intended for students completing the M.E. degree. The student is expected to identify all aspects of the M.E. curriculum and an integrative, descriptive systems approach. The project activity requires the student to describe the development, design construction, maintenance and operation process for an actual facility; to evaluate the performance of the facility with respect to functional and operational objectives; and to examine alternative solutions. Specific areas of study are selected by the student and approved by the faculty member. The work may be accomplished by individuals or small groups of students working on the same project.

Units: 3

Prerequisites:

consent of instructor

CE 596: Graduate Seminar

Seminars on current issues and state-of-the-art research in civil and environmental engineering given by guest speakers, faculty, and students.

Units: 0

CE 599: M.S. Thesis

Research study at the M.S. level.

Units: 3

CE 699: Ph.D. Thesis

Research study at the Ph.D. level.

Units: 3

CE 5621: Open Channel Hydraulics

This course begins with fundamentals of free surface flow, and includes engineering and environmental applications. Development of basic principles, including specific energy, momentum and critical flow. Rapidly varied, uniform and gradually varied steady flow phenomena and analysis. Density-stratified flow. Similitude considerations for hydraulic models. Optional topics: dispersion and heat transfer to atmosphere. Course may be offered by special arrangement.

Units: 3

Climate Change Adaptation

IGS 501: Theorizing Place, Community, and Global Environmental Change

This proseminar explores the relationship between global and local contexts at different scales, with a focus on how communities can change and thrive under conditions of global environmental change. We explore the theoretical and practical understandings of, and strategies for, cultural and technological change as enacted in specific places by people whose identities, practices, and values vary widely, and who are impacted differentially by the historical, structural, and environmental conditions that they both create and encounter. Students will complete an individual depth assignment that could be a substantive research paper, project proposal, or community service activity for the degree portfolio. They will also participate in the DIGS/ Global School Speaker Series, and will use that content to engage with course readings as well as their own projects. Recommended background: Admission to the CCA program, MS or BS/MS track.

Units: 3

IGS 505: Qualitative Methods for Community-Engaged Research

This course advances student knowledge of research design and methods, emphasizing frameworks, strategies, and qualitative methods for community-engaged studies. In this course, students engage with alternative frameworks, including community based (participatory) research and citizen science, to build understandings about the continuum of the research process. Process elements include planning and design, implementation, evaluation, dissemination, and assessing policy implications, as they are applied in deeply collaborative action research settings. This course explores strengths, weaknesses, and challenges of different data gathering and analytic methods through exploration of prior studies, and considers how these research approaches intersect with social, cultural, and institutional practices and ethical standards. Students work in teams to develop proposals for a Graduate Qualifying Project that addresses the needs of an outside project partner. Recommended background: Admission to the CCA MS program, completion of social science research methods course (e.g., ID 2050 or equivalent), or permission of instructor.

Units: 2

IGS 510: Human Dimensions of Global Environmental Change

This course provides the groundwork for understanding the historical, sociocultural, and political-economic impacts of climate change in the Anthropocene. Building upon a basic understanding of climate science, this course addresses how global environmental change is mediated by social, political, economic and cultural systems. Case studies are used to scrutinize how efforts to mitigate and adapt to impacts can overcome or exacerbate existing inequities. Through a focus on how responses emerge in specific places and times, students explore how they can play a role in efforts by communities around the world as these communities adapt to existing and developing environmental changes, face decisions about retreat, and plan for the future. Recommended background: Admission to the CCA MS or BS/MS program, as well as CE 575, or another course in climate science, or permission of instructor.

Units: 2

IGS 545: Climate Change: Vulnerability and Mitigation

Taking climate change as a starting point, this course introduces students to a wide range of climate change conditions, human responses to those conditions, and points toward the need for deeper understanding of human-environment relationships. The course will draw from Geography, Economics, Global Environmental Change, and other cross cutting disciplines for theory and case studies. Examples of climate change risks and mitigation efforts will come from the developed and developing world and will include both urban and rural examples. Assessment techniques include small group projects, case-based testing, and in class and online discussions. Recommended background: IGS 510 and CE 575 or permission of instructor.

Units: 3

IGS 590: Capstone Seminar: Comparative Climate Action

This seminar analyzes core themes of the Community Climate Adaptation Program during the students' third and final semester. Bridging the disciplines of geography, anthropology, and civil & environmental engineering, we draw together the insights and experiences learned by technical and social science students during the first two semesters of the program. Through a combination of readings, case studies, and an individual depth project, the course provides an opportunity for students to revisit theoretical frameworks for climate adaptation strategies in a way that is informed by their place-based applied research in diverse places internationally. We explore similarities and differences observed in different localities across scales in order to strengthen an empirically-grounded, comparative, and holistic analysis of community climate adaptation. In doing so, we investigate both positive resonances between theoretical frameworks and demonstrated outcomes in discrete places, while we also critically probe any gaps, tensions, and surprises that may emerge from the GQP fieldwork. Participation in the DIGS/GS speaker series is required for this course, as the topics and guests will provide additional content for consideration. Recommended background: Completion of 12 credits in 3 Core CCA courses and 8 credits of GQP.

Units: 3

IGS 595: Graduate Qualifying Project: Research

(3 to 8 Credits) The eight-credit graduate qualifying project (GQP), typically done in teams, is to be carried out in cooperation with an external partner, and it is overseen by two faculty members representing both the Department of Integrated and Global Studies and Civil & Environmental Engineering. Student teams seek to answer a climate adaptation question identified and explained by the external partner. The student teams conduct applied research using goals, objectives, and methods developed in the core Methods courses for the CCA program, based on this driving question and under the joint guidance of two WPI faculty advisors and the external partner. The course is full-time and structured by two weekly meetings with the faculty advisors and external partner. Professional development skills, such as oral and written communication, teamwork, leadership, and collaborative problem-solving will be practiced as the research is completed across a full semester. Recommended background: Completion of CCA core classes (except IGS 590 and IGS 599) and permission of instructor.

IGS 599: Graduate Qualifying Project: Conference

(1 to 3 Credits) The graduate qualifying project (GQP), typically done in teams, is to be carried out in cooperation with a sponsor or external partner, and it is overseen by two faculty members representing both the Department of Integrated and Global Studies and Civil & Environmental Engineering. This three-credit Conference course integrates theory and practice of community climate adaptation strategies, and it should address and build upon the frameworks and tools acquired in the research phase of the program. Deliverables for this course consist of a written report and public presentation to the WPI community and external partner.

Prerequisites:
IGS 595 Graduate Qualifying Project: Research

Computer Science

BCB 502/CS 582: Biovisualization

This course uses interactive visualization to explore and analyze data, structures, and processes. Topics include the fundamental principles, concepts, and techniques of visualization and how visualization can be used to analyze and communicate data in domains such as biology. Students will be expected to design and implement visualizations to experiment with different visual mappings and data types, and will complete a research oriented project.
Units: 3
Prerequisites:
experience with programming (especially JavaScript), databases, and data structures. Students may not receive credit for both BCB 502 and BCB 4002.

BCB 503/CS 583: Biological and Biomedical Database Mining

This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources, including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining.
Units: 3
Prerequisites:
Strong programming skills, an undergraduate or graduate course in algorithms, an undergraduate course in statistics, and one or more undergraduate biology courses

CS/DS 541: Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them — such as back-propagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing.

Units: 3

Prerequisites:

Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223)

CS/DS 547: Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model.

Units: 3

Prerequisites:

statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

CS/RBE 526: Human-Robot Interaction

This course focuses on human-robot interaction and social robot learning, exploring the leading research, design principles and technical challenges we face in developing robots capable of operating in real-world human environments. The course will cover a range of multidisciplinary topics, including physical embodiment, mixed-initiative interaction, multi-modal interfaces, human-robot teamwork, learning algorithms, aspects of social cognition, and long-term interaction. These topics will be pursued through independent reading, class discussion, and a final project.

Units: 3

Prerequisites:

Mature programming skills and at least undergraduate level knowledge of Artificial Intelligence, such as CS 4341. No hardware experience is required

CS/RBE 549: Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images.

Units: 3

Prerequisites:

CS 534, CS 543, CS 545, or the equivalent of one of these courses

CS/SEME 565: User Modeling

User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user.

Units: 3

Prerequisites:

Knowledge of probability

CS/SEME 566: Graphical Models for Reasoning Under Uncertainty

This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one.

Units: 3

Prerequisites:

CS 534 Artificial Intelligence or permission of the instructor

CS/SEME 567: Empirical Methods for Human-Centered Computing

This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research.

Units: 3

Prerequisites:

MA 511 Applied Statistics for Engineers and Scientists or permission of instructor

CS/SEME 568: Artificial Intelligence for Adaptive Educational Technology

Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system.

Units: 3

Prerequisites:

CS 534 Artificial Intelligence or permission of the instructor

CS 502: Operating Systems

The design and theory of multiprogrammed operating systems, concurrent processes, process communication, input/output supervisors, memory management, resource allocation and scheduling are studied.

Units: 3

Prerequisites:

knowledge of computer organization and elementary data structures, and a strong programming background

CS 503: Foundations of Computer Science

This is the study of mathematical foundations of computing. Topics include finite automata and regular languages, pushdown automata and context-free languages, Turing machines and decidability, and an introduction to computational complexity.

Units: 3

Prerequisites:

Knowledge of discrete mathematics and algorithms at the undergraduate level, and some facility with reading and writing mathematical proofs

CS 504: Analysis of Computations and Systems

The following tools for the analysis of computer programs and systems are studied: probability, combinatorics, the solution of recurrence relations and the establishment of asymptotic bounds. A number of algorithms and advanced data structures are discussed, as well as paradigms for algorithm design.
Units: 3
Prerequisites:
CS 5084 or equivalent

CS 509: Design of Software Systems

This course introduces students to a methodology and specific design techniques for team-based development of a software system. Against the backdrop of the software engineering life-cycle, this course focuses on the object-oriented paradigm and its supporting processes and tools. Students will be exposed to industrial-accepted standards and tools, such as requirements elicitation, specification, modeling notations, design patterns, software architecture, integrated development environments and testing frameworks. Students will be expected to work together in teams in the complete specification, implementation and testing of a software application.
Units: 3
Prerequisites:
knowledge of a recursive high-level language and data structures. An undergraduate course in software engineering is desirable.

CS 513: Computer Networks

This course provides an introduction to the theory and practice of the design of computer and communications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types including local area and wide area networks are introduced, as are evolving network technologies. The theory, design and performance of local area networks are emphasized. The course includes an introduction to queueing analysis and network programming.
Units: 3
Prerequisites:
knowledge of the C programming language is assumed. CS 504 or equivalent background in CS 5084 or CS 584

CS 514/ECE 572: Advanced Systems Architecture

See ECE 572 course description on page 104.
Units: 3

CS 521: Logic in Computer Science

This course is an introduction to mathematical logic from a computer science perspective. Topics covered include the exploration of model theory, proof theory, and decidability for propositional and first-order classical logics, as well as various non-classical logics that provide iseful tools for computer science (such as temporal and intuitionistic logics). The course stresses the application of logic to various areas of computer science such as computability, theorem proving, programming languages, specification,and verification. The specific applications included will vary by instructor.
Units: 3
Prerequisites:
CS 503, or equivalent background in basic models of computation

CS 522/MA 510: Numerical Methods

See MA 510 course description.
Units: 3

CS 525: Topics in Computer Science

A topic of current interest is covered in detail. Please consult the department for a current listing of selected topics in this area.
Units: 3
Prerequisites:
vary with topic

CS 528: Mobile and Ubiquitous Computing

This course acquaints participants with the fundamental concepts and state-of-the-art computer science research in mobile and ubiquitous computing. Topics covered include mobile systems issues, human activity and emotion sensing, location sensing, mobile HCI, mobile social networking, mobile health, power saving techniques, energy and mobile performance measurement studies and mobile security. The course consists of weekly presentations on current advanced literature, discussions and a term project. The term project involves implementing research ideas on a mobile device such as a smartphone.
Units: 3
Prerequisites:
CS 502 or an equivalent graduate level course in Operating Systems, and CS 513 or an equivalent graduate level course in Computer Networks, and proficiency in a high level programming language

CS 529: Multimedia Networking

This course covers basic and advanced topics related to using computers to support audio and video over a network. Topics related to multimedia will be selected from areas such as compression, network protocols, routing, operating systems and human computer interaction. Students will be expected to read assigned research papers and complete several programming intensive projects that illustrate different aspects of multimedia computing.

Units: 3

Prerequisites:

CS 502 and CS 513 or the equivalent and strong programming skills

CS 533/ECE 581: Modeling and Performance Evaluation of Network and Computer Systems

Methods and concepts of computer and communication network modeling and system performance — evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; work load characterization; performance evaluation problems.

Units: 3

Prerequisites:

CS 5084 or CS 504 or equivalent background in probability and some background in statistics

CS 534: Artificial Intelligence

This course gives a broad survey of artificial intelligence. The course will cover methods from search, probabilistic reasoning, and learning, among other topics. Selected topics involving the applications of these tools are investigated. Such topics might include natural language understanding, scene understanding, game playing, and planning.

Units: 3

Prerequisites:

familiarity with data structures and a high-level programming language

CS 535: Advanced Topics in Operating Systems

This course discusses advanced topics in the theory, design and implementation of operating systems. Topics will be selected from such areas as performance of operating systems, distributed operating systems, operating systems for multiprocessor systems and operating systems research.

Units: 3

Prerequisites:

CS 502 and either CS 5084, CS 504, CS 584, or equivalent background in probability

CS 536: Programming Language Design

This course discusses the fundamental concepts and general principles underlying current programming languages and models. Topics include control and data abstractions, language processing and binding, indeterminacy and delayed evaluation, and languages and models for parallel and distributed processing. A variety of computational paradigms are discussed: functional programming, logic programming, object-oriented programming and data flow programming.

Units: 3

Prerequisites:

student is expected to know a recursive programming language and to have an undergraduate course in data structures

CS 538: Knowledge-Based Systems

The course will review knowledge-based problemsolving systems. It will concentrate on an analysis of their architecture, knowledge and problemsolving style in order to classify and compare them. An attempt will be made to evaluate the contribution to our understanding of problems that such systems can tackle.

Units: 3

Prerequisites:

CS 534 or equivalent or permission of the instructor

CS 539: Machine Learning

The focus of this course is machine learning for knowledge-based systems. It will include reviews of work on similarity-based learning (induction), explanation-based learning, analogical and case-based reasoning and learning, and knowledge compilation. It will also consider other approaches to automated knowledge acquisition as well as connectionist learning.

Units: 3

Prerequisites:

CS 534 or equivalent, or permission of the instructor

CS 540: Artificial Intelligence in Design

The main goal of this course is to obtain a deeper understanding of what "design" is, and how AI might be used to support and study it. Students will examine some of the recent AI-based work on design problem-solving. The course will be run in seminar style, with readings from the current literature and with student presentations. The domains will include electrical engineering design, mechanical engineering design, civil engineering design and software design (i.e., automatic programming). This course will be of interest to those wanting to prepare for research in design, or those wishing to increase their understanding of expert systems. Graduate students from departments other than computer science are welcome.

Units: 3

Prerequisites:

knowledge of artificial intelligence is required. This can only be waived with permission of the instructor

CS 542: Database Management Systems

An introduction to the theory and design of data-base management systems. Topics covered include internals of database management systems, fundamental concepts in database theory, and database application design and development. In particular, logical design and conceptual modeling, physical database design strategies, relational data model and query languages, query optimization, transaction management and distributed databases. Typically there are hands-on assignments and/or a course project. Selected topics from the current database research literature may be touched upon as well.

Units: 3

Prerequisites:

CS 5084 would be helpful

CS 543: Computer Graphics

This course examines typical graphics systems, both hardware and software; design of low-level software support for raster displays; 3-D surface and solids modeling; hidden line and hidden surface algorithms; and realistic image rendering including shading, shadowing, reflection, refraction and surface texturing.

Units: 3

Prerequisites:

familiarity with data structures, a recursive high-level language and linear algebra. CS 509 would be helpful

CS 544: Compiler Construction

A general approach to the design of language processors is presented without regard for either the source language or target machine. All phases of compilation and interpretation are investigated in order to give the student an appreciation for the overall construction of a compiler. Typical projects may include implementation of a small compiler for a recursive or special-purpose language.

Units: 3

Prerequisites:

knowledge of several higher-level languages and at least one assembly language. The material in CS 503 is helpful

CS 545/ECE 545: Digital Image Processing

This course presents fundamental concepts of digital image processing and an introduction to machine vision. Image processing topics will include visual perception, image formation, imaging geometries, image transform theory and applications, enhancement, restoration, encoding and compression. Machine vision topics will include feature extraction and representation, stereo vision, model-based recognition, motion and image flow, and pattern recognition. Students will be required to complete programming assignments in a high-level language.

Units: 3

Prerequisites:

working knowledge of undergraduate level signal analysis and linear algebra; familiarity with probability theory is helpful but not necessary

CS 546: Human-Computer Interaction

This course prepares graduate students for research in human-computer interaction. Topics include the design and evaluation of interactive computer systems, basic psychological considerations of interaction, interactive language design, interactive hardware design and special input/output techniques. Students are expected to present and review recent research results from the literature, and to complete several projects.

Units: 3

Prerequisites:

students are expected to have mature programming skills. Knowledge of software engineering would be an advantage

CS 548: Knowledge Discovery and Data Mining

This course presents current research in Knowledge Discovery in Databases (KDD) dealing with data integration, mining, and interpretation of patterns in large collections of data. Topics include data warehousing and data preprocessing techniques; data mining techniques for classification, regression, clustering, deviation detection, and association analysis; and evaluation of patterns minded from data. Industrial and scientific applications are discussed.

Units: 3

Recommended Background:

Background in artificial intelligence, databases, and statistics at the undergraduate level, or permission of the instructor. Proficiency in a high level programming language.

CS 557: Software Security Design and Analysis

Software is responsible for enforcing many central security goals in computer systems. These goals include authenticating users and other external principals, authorizing their actions, and ensuring the integrity and confidentiality of their data. This course studies how to design, implement, and analyze mechanisms to enforce these goals in both web systems and programs in traditional languages. Topics include: identifying programming choices that lead to reliable or flawed security outcomes, successful and unsuccessful strategies for incorporating cryptography into software, and analysis techniques that identify security vulnerabilities. The course will cover both practical and theoretical aspects of secure software, and will include a substantial secure software design project.

Units: 3

Prerequisites:

Programming and software engineering experience (commensurate with an undergraduate Computer Science major), and background in foundational models of computing systems (on par with CS 5003 or CS 503)

CS 558: Computer Network Security

This course covers core security threats and mitigations at the network level. Topics include: denial-of-service, network capabilities, intrusion detection and prevention systems, worms, botnets, Web attacks, anonymity, honeypots, cybercrime (such as phishing), and legality and ethics. The course prepares students to think broadly and concretely about network security; it is not designed to teach students low-level tools for monitoring or maintaining system security. Assignments and projects will assess each student's ability to think both conceptually and practically about network security.

Units: 3

Prerequisites:

a strong background in computer networking and systems, either at the undergraduate or graduate level, and moderate programming experience

CS 559: Advanced Topics in Theoretical Computer Science

This course has an instructor-dependent syllabus.

Units: 3

CS 561: Advanced Topics in Database Systems

This course covers modern database and information systems as well as research issues in the field. Topics and systems covered may include object-oriented, workflow, active, deductive, spatial, temporal and multimedia databases. Also discussed will be recent advances in database systems such as data mining, online analytical processing, data warehousing, declarative and visual query languages, multimedia database tools, web and unstructured data sources, and client-server and heterogeneous systems. The specific subset of topics for a given course offering is selected by the instructor. Research papers from recent journals and conferences are used. Group project required.
Units: 3
Prerequisites:
CS 542 or equivalent. Expected background includes a knowledge of relational database systems

CS 562: Advanced Topics in Software Engineering

This course focuses on the nondesign aspects of software engineering. Topics may include requirements specification, software quality assurance, software project management and software maintenance.
Units: 3
Prerequisites:
CS 509

CS 563

CS 564: Advanced Topics in Computer Security

This course examines one or more selected current issues in the area of computer security. Specific topics covered are dependent on the instructor. Potential topics include: modeling and analyzing security protocols, access-control, network security, and human-centered security.
Units: 3
Prerequisites:
a graduate level security course or equivalent experience.

CS 571: Case Studies in Computer Security

This course examines security challenges and failures holistically, taking into account technical concerns, human behavior, and business decisions. Using a series of detailed case studies, students will explore the interplay among these dimensions in creating secure computing systems and infrastructure. Students will also apply lessons from the case studies to emerging secure-systems design problems. The course requires active participation in class discussions, presentations, and writing assignments. It does not involve programming, but assumes that students have substantial prior experience with security protocols, attacks, and mitigations at the implementation level. This course satisfies the behavioral component of the M.S. specialization in computer security.
Units: 3
Prerequisites:
A prior course or equivalent experience in technical aspects of computer security, at either the software or systems level

CS 573: Data Visualization

This course exposes students to the field of data visualization, i.e., the graphical communication of data and information for the purposes of presentation, confirmation, and exploration. The course introduces the stages of the visualization pipeline. This includes data modeling, mapping data attributes to graphical attributes, visual display techniques, tools, paradigms, and perceptual issues. Students learn to evaluate the effectiveness of visualizations for specific data, task, and user types. Students implement visualization algorithms and undertake projects involving the use of commercial and public-domain visualization tools. Students also read papers from the current visualization literature and do classroom presentations.
Units: 3
Prerequisites:
a graduate or undergraduate course in computer graphics

CS 577/ECE 537: Advanced Computer and Communications Networks

This course covers advanced topics in the theory, design and performance of computer and communications networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queueing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies.
Units: 3
Prerequisites:
CS 533/ECE 581 and either CS 513 or ECE 506

CS 578/ECE 578: Cryptography and Data Security

See ECE 578 course description.
Units: 3

CS 582/BCB 502: Biovisualization

This course uses interactive visualization to explore and analyze data, structures, and processes Topics include the fundamental principles, concepts, and techniques of visualization and how visualization can be used to analyze and communicate data in domains such as biology. Students will be expected to design and implement visualizations to experiment with different visual mappings and data types, and will complete a research oriented project.

Units: 3

Prerequisites:

experience with programming (especially JavaScript), databases, and data structures. Students may not receive credit for both CS 582 and CS 4802.

CS 583/BCB 503: Biological and Biomedical Database Mining

This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining.

Units: 3

Prerequisites:

strong programming skills, an undergraduate or graduate course in algorithms, an undergraduate course in statistics, and one or more undergraduate biology courses.) Students may not receive credit for both CS 583 and CS 4803.

CS 584: Algorithms: Design and Analysis

This covers the same material as CS5084 though at a more advanced level. As background, students should have experience writing programs in a recursive, high-level language and should have the background in mathematics that could be expected from a B.S. in Computer Science.

Units: 3

CS 585/DS 503: Big Data Management

Big Data Management deals with emerging applications in science and engineering disciplines that generate and collect data at unprecedented speed, scale, and complexity that need to be managed and analyzed efficiently. This course introduces the latest techniques and infrastructures developed for big data management including parallel and distributed database systems, map-reduce infrastructures, scalable platforms for complex data types, stream processing systems, and cloud-based computing. Query processing, optimization, access methods, storage layouts, and energy management techniques developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies.

Units: 3

Prerequisites:

A beginning course in databases at the level of CS 4432 or equivalent knowledge, and programming experience.

CS 586/DS 504: Big Data Analytics

Big Data Analytics addresses the obstacle that innovation and discoveries are no longer hindered by the ability to collect data, but by the ability to summarize, analyze, and discover knowledge from the collected data in a scalable fashion. This course covers computational techniques and algorithms for analyzing and mining patterns in large-scale datasets. Techniques studied address data analysis issues related to data volume (scalable and distributed analysis), data velocity (high-speed data streams), data variety (complex, heterogeneous, or unstructured data), and data veracity (data uncertainty). Techniques include mining and machine learning techniques for complex data types, and scale-up and scale-out strategies that leverage big data infrastructures. Real-world applications using these techniques, for instance social media analysis and scientific data mining, are selectively discussed. Students are expected to engage in hands-on projects using one or more of these technologies.

Units: 3

Prerequisites:

A beginning course in databases and a beginning course in data mining, or equivalent knowledge, and programming experience.

CS 587/ECE 588: Cyber Security Capstone Experience

To reduce cyber security theory to practice, the capstone project has students apply security concepts to real-world problems. The capstone represents a substantial evaluation of the student's cyber security experience. Students are encouraged to select projects with practical experience relevant to their career goals and personal development. In the capstone, students will propose a project idea in writing with concrete milestones, receive feedback, and pursue the proposal objectives. Since cyber security is a collaborative discipline, students are encouraged to work in teams.

This course is a degree requirement for the Professional Master's in Cyber Security (PM-SEC) and may not be taken before completion of 21 credits in the program. Given its particular role, this course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. Students outside the PM-SEC program must get the instructor's approval before taking this course for credit.
Units: 3

CS 588: Computer Science Capstone Experience

The capstone represents a substantial evaluation of the student's computer science experience. Students are encouraged to select projects with practical experience relevant to their career goals and personal development. In the capstone, students will propose a project idea in writing with concrete milestones, receive feedback, and pursue the proposal objectives. Students are encouraged to work in teams.

This course is a degree requirement for the Master of Computer Science (MCS) and may not be taken before completion of 21 credits in the program. Given its particular role, this course may not be used to satisfy degree requirements for a BS, MS, or PhD degree in Computer Science or a minor in Computer Science. It may not be taken by students in other degree programs.
Units: 3

CS 598: Directed Research

Units: 3

CS 599: Master's Thesis

Units: 3

CS 673/ECE 673: Advanced Cryptography

This course provides deeper insight into areas of cryptography which are of great practical and theoretical importance. The three areas treated are detailed analysis and the implementation of cryptoalgorithms, advanced protocols, and modern attacks against cryptographic schemes. The first part of the lecture focuses on public key algorithms, in particular ElGamal, elliptic curves and Diffie-Hellman key exchange. The underlying theory of Galois fields will be introduced. Implementation of performance security aspects of the algorithms will be looked at. The second part of the course deals with advanced protocols. New schemes for authentication, identification and zero-knowledge proof will be introduced. Some complex protocols for real-world application— such as key distribution in networks and for smart cards—will be introduced and analyzed. The third part will look into state-of-the-art cryptoanalysis (i.e., ways to break cryptosystems). Brute force attacks based on special purpose machines, the baby-step giant-step and the Pohlig-Hellman algorithms will be discussed.
Units: 3
Prerequisites:
CS 578/ ECE 578 or equivalent background

CS 699: Ph.D. Dissertation

Units: 3

CS 5003: Foundations of Computer Science: an Introduction

This is the study of mathematical foundations of computing, at a slower pace than that of CS 503 and with correspondingly fewer background assumptions. Topics include finite automata and regular languages, pushdown automata and context-free languages, Turing machines and decidability, and an introduction to computational complexity.

Units: 3

Prerequisites:

an undergraduate course in discrete mathematics

CS 5007: Introduction to Applications of Computer Science with Data Structures and Algorithms

This is an introductory graduate course teaching core computer science topics typically found in an undergraduate Computer Science curriculum, but at a graduate-level pace. It is primarily intended for students with little formal preparation in Computer Science to gain experience with fundamental Computer Science topics. After a review of programming concepts the focus of the course will be on data structures from the point of view of the operations performed upon the data and to apply analysis and design techniques to non-numeric algorithms that act on data structures. The data structures covered include lists, stacks, queues, trees and graphs. Projects will focus on the writing of programs to appropriately integrate data structures and algorithms for a variety of applications. This course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. It may satisfy the requirements for other degree programs at the discretion of the program review committee for the particular degree.

Units: 3

Prerequisites:

Experience with at least one high-level programming language such as obtained in an undergraduate programming course

CS 5008: Introduction to Systems and Network Programming

This course is focused on significant programming projects and provides an overview of the principles of computer networks and a general-purpose operating system. The course provides the student with an understanding of the basic components of an operating system, including processes, synchronization and memory management. The course exposes students to the Internet protocol suite networking layers while providing an introduction into topics such as wireless networking and Internet traffic considerations. The objective is to focus on an understanding of fundamental concepts of operating systems and computer network architecture from a design and performance perspective.

Students will be expected to design and implement a variety of programming projects to gain an appreciation of the design of operating systems and network technologies. This course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. It may satisfy the requirements for other degree programs at the discretion of the program review committee for the particular degree.

Units: 3

Prerequisites:

Experience with at least one high-level programming language such as obtained in CS 5007.

CS 5084: Introduction to Algorithms: Design and Analysis

This course is an introduction to the design, analysis and proofs of correctness of algorithms. Examples are drawn from algorithms for many areas. Analysis techniques include asymptotic worst case and average case, as well as amortized analysis. Average case analysis includes the development of a probability model. Techniques for proving lower bounds on complexity are discussed, along with NP-completeness. Note: students with a strong background in design and analysis of computer systems, at the level equal to a B.S. in computer science, should not take CS 5084 and should consider taking CS 504 or CS 584.

Units: 3

Prerequisites:

an undergraduate knowledge of discrete mathematics and data structures.

DS/CS 541: Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them — such as back-propagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing.

Units: 3

Prerequisites:

Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223

DS/CS 547: Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model.

Units: 3

Prerequisites:

statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

ECE 530/CS 530: High Performance Networks

This course is an in-depth study of the theory, design and performance of high-speed networks. Topics include specific high-performance network architectures and protocols and emerging technologies including multimedia networks and quality-of-service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queueing models.

Units: 3

Prerequisites:

ECE 506/CS 513

ECE 588/CS 587: Cyber Security Capstone Experience

To reduce cyber security theory to practice, the capstone project has students apply security concepts to real-world problems. The capstone represents a substantial evaluation of the student's cyber security experience. Students are encouraged to select projects with practical experience relevant to their career goals and personal development. In the capstone, students will propose a project idea in writing with concrete milestones, receive feedback, and pursue the proposal objectives. Since cyber security is a collaborative discipline, students are encouraged to work in teams.

This course is a degree requirement for the Professional Master's in Cyber Security (PM-SEC) and may not be taken before completion of 21 credits in the program. Given its particular role, this course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. Students outside the PM-SEC program must get the instructor's approval before taking this course for credit.
Units: 3

RBE/CS 549: Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images.
Units: 3
Prerequisites:
CS 534, CS 543, CS 545, or the equivalent of one of these courses

SEME/CS 565: User Modeling

User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user.
Units: 3
Prerequisites:
Knowledge of probability

SEME/CS 566: Graphical Models for Reasoning Under Uncertainty

This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one.
Units: 3
Prerequisites:
CS 334 Artificial Intelligence or permission of the instructor

SEME/CS 567: Empirical Methods for Human-Centered Computing

This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research.

Units: 3

Prerequisites:

MA 311 Applied Statistics for Engineers and Scientists or permission of instructor

SEME/CS 568: Artificial Intelligence for Adaptive Educational Technology

Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system.

Units: 3

Prerequisites:

CS 534 Artificial Intelligence or permission of the instructor

Data Science

CS/DS 541: Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them — such as back-propagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing.

Units: 3

Prerequisites:

Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223)

CS/DS 547: Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model.

Units: 3

Prerequisites:

statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

DS/CS 541: Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them — such as back-propagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing.

Units: 3

Prerequisites:

Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223

DS/CS 547: Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model.

Units: 3

Prerequisites:

statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

DS/ECE 577: Machine Learning in Cybersecurity

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.

Units: 3

DS/MA 517: Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data.

Units: 3

Prerequisites:

Some knowledge of integral and differential calculus is recommended.

DS 501: Introduction to Data Science

Introduction to Data Science provides an overview of Data Science, covering a broad selection of key challenges in and methodologies for working with big data. Topics to be covered include data collection, integration, management, modeling, analysis, visualization, prediction and informed decision making, as well as data security and data privacy. This introductory course is integrative across the core disciplines of Data Science, including databases, data warehousing, statistics, data mining, data visualization, high performance computing, cloud computing, and business intelligence. Professional skills, such as communication, presentation, and storytelling with data, will be fostered. Students will acquire a working knowledge of data science through hands-on projects and case studies in a variety of business, engineering, social sciences, or life sciences domains. Issues of ethics, leadership, and teamwork are highlighted.

Units: 3

Prerequisites:

None beyond meeting the Data Science admission criteria.

DS 502/MA 543: Statistical Methods for Data Science

Statistical Methods for Data Science surveys the statistical methods most useful in data science applications. Topics covered include predictive modeling methods, including multiple linear regression, and time series, data dimension reduction, discrimination and classification methods, clustering methods, and committee methods. Students will implement these methods using statistical software.

Units: 3

Prerequisites:

DS 517/ MA 517, Statistics at the level of MA 2611 and MA 2612 and linear algebra at the level of MA 2071.

DS 503/CS 585: Big Data Management

Big Data Management deals with emerging applications in science and engineering disciplines that generate and collect data at unprecedented speed, scale, and complexity that need to be managed and analyzed efficiently. This course introduces the latest techniques and infrastructures developed for big data management including parallel and distributed database systems, map-reduce infrastructures, scalable platforms for complex data types, stream processing systems, and cloud-based computing. Query processing, optimization, access methods, storage layouts, and energy management techniques developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies.

Units: 3

Prerequisites:

A beginning course in databases at the level of CS 4432 or equivalent knowledge, and programming experience.

DS 504/CS 586: Big Data Analytics

Big Data Analytics addresses the obstacle that innovation and discoveries are no longer hindered by the ability to collect data, but by the ability to summarize, analyze, and discover knowledge from the collected data in a scalable fashion. This course covers computational techniques and algorithms for analyzing and mining patterns in large-scale datasets. Techniques studied address data analysis issues related to data volume (scalable and distributed analysis), data velocity (high-speed data streams), data variety (complex, heterogeneous, or unstructured data), and data veracity (data uncertainty). Techniques include mining and machine learning techniques for complex data types, and scale-up and scale-out strategies that leverage big data infrastructures. Real-world applications using these techniques, for instance social media analysis and scientific data mining, are selectively discussed. Students are expected to engage in hands-on projects using one or more of these technologies.
Units: 3
Prerequisites:
A beginning course in databases and a beginning course in data mining, or equivalent knowledge, and programming experience.

DS 595: Special Topics in Data Science

Special Topics in Data Science is course offering that will cover a topic of current interest in detail. This serves as a flexible vehicle to provide a one-time offering of topics of current interest as well as to offer new topics before they are made into a permanent course.
Units: 3
Prerequisites:
will vary with topic.

DS 596: Independent Study

Independent Study, as the name suggests, is a course that allows a student to study a chosen topic in Data Science under the guidance of a faculty member affiliated with the Data Science program. The student must produce a written report to satisfy the course requirement.
Units: 3

DS 597: Directed Research

Directed Research study, conducted under the guidance of a faculty member affiliated with the Data Science Program, investigates the challenges and techniques central to data science, and aims to develop novel approaches and techniques towards solving these challenges. The student who chooses this course must produce a written report to fulfil the course requirement.
Units: 3

DS 598: Graduate Qualifying Project

This 3-credit graduate qualifying project, done in teams, can be taken a second time for credit with permission by the instructor, up to a total of 6 credits. The project is to be carried out in cooperation with a sponsor or industrial partner. It must be overseen by a faculty member affiliated with the Data Science Program. This offering integrates theory and practice of Data Science, and includes the utilization of tools and techniques acquired in the Data Science Program. In addition to a written report, this project must be presented in a formal presentation to faculty of the Data Science program and sponsors. Professional development skills, such as communication, teamwork, leadership, and collaboration, along with storytelling, will be practiced.
Units: 3
Prerequisites:
DS students should have completed at least 24 credits of the DS MS degree, or consent of the instructor, before starting the GQP project class. DS students seeking to take this course a second time for credits, up to a total of 6 credits, must get the instructor's approval. Non-DS students must get the instructors approval before taking this course for any number of credits.

DS 599: Master's Thesis in Data Science

The Master's Thesis in Data Science consists of a research and development project worth a minimum of 9 graduate credit hours and is advised by a faculty member affiliated with the Data Science Program. A thesis proposal must be approved by the DS Program Review Board and the student's advisor, before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the DS faculty in a public presentation.
Units: 9

DS 699: Dissertation Research.

Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations.
Units: 3
Prerequisites:
Consent of Dissertation Advisor

DS 5900: Data Science Internship

The internship is an elective-credit option designed to provide an opportunity to put into practice the principles studied in previous Data Science courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization, generally from off campus and must be approved and advised by a core faculty member in the Data Science program. The internship must include proposal, design and documentation phases. Following the internship, the student will report on his or her internship activities in a mode outlined by the supervising faculty member. Students are limited to counting a maximum of 3 internship credits towards their degree requirements for the M.S. degree in Data Science. We expect a full-time graduate student to take on only part-time (20 hours or less of) internship work during the regular academic semester, while a full-time internship of 40 hours per week is appropriate during the summer semester as long as the student does not take a full class load at the same time. Internship credit cannot be used towards a certificate degree in Data Science. The internship may not be completed at the students current place of employment.
Units: 0
Prerequisites:
Registration for internship credit requires prior approval and signature by the academic advisor.

ECE/DS 577: Machine Learning in Cybersecurity

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.
Units: 3

MA/DS 517: Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data.
Units: 3
Prerequisites:
Some knowledge of integral and differential calculus is recommended.

Development

DEV 501: Social Innovation and Global Development

Social Innovation and Global Development provides a broad overview of the program. We will touch on many of the themes that will be explored in depth in the core courses. These themes include but are not limited to: design thinking, cross-cultural design, ethics in design, and visual expression. We will also employ team building exercises bring the cohort together as a cohesive group. The mornings will be spent in interactive classroom experiences where students will engage in seminar discussions, small group activities, and feedback sessions. This course will take place in the two weeks leading up to the students first semester in the program. The course will run two weeks, for approximately six hours per day, Monday through Friday.
Units: 3

DEV 502: Design for Social Change

Everyone is entitled to good design, without distinction of any kind. Race, color, sex, language, religion, political or other opinions, national or social origins, property, birth or other status should have effective visual communication. Social Impact Design Course is a place where student designers learn to create "good design" for the "good of others." Community engagement through community-based design projects is just one aspect of the course. Students will learn additional practice skills in design thinking and cause branding. This course explores various community and professional practices when designing for social change. Through community-based projects with non-profit organizations, students explore the many roles creative professionals can play when executing socially-minded work. Students will be challenged to expand their comprehension of design problem solving for new audiences. Design teams will develop skills in design methodology for visual communication: identifying problems, design research, ideation, and implementation.
Units: 3

DEV 510: Design Studio 1

This studio course introduces students to a variety of design case studies from developing world infrastructure projects, to human computer interaction, autonomous vehicles, and others to give students an opportunity to explore and critique design processes and to develop a sense of their own approach with some depth.
Units: 3

DEV 520: Design Studio 2

This studio course is taken in E(I) term. Here students will begin to develop their own GQP or thesis projects. They will share their work with their peers in weekly feedback sessions. Faculty will act as mentors who push the students toward project and process clarity. For students traveling abroad the studio will provide an opportunity to raise and explore important cultural considerations.
Units: 3

DEV 530: Ethics and Social Justice in Science, Engineering, and Development

DEV 540: Research Methods

DEV 595: Special Topics in Design for Science, Technology and Innovation

This course will allow flexibility for faculty to offer courses on topics of current interest.
Units: 3
Prerequisites:
will vary on course content

DEV 596: Independent Study

This course will allow a student(s) to study a certain topic under the guidance of an affiliated faculty member. The student must produce an appropriate paper (e.g., conceptual or empirical) from this experience.
Units: 3

DEV 597: Directed Research

Directed research allows students the opportunity to engage in a research project that is related to a member of faculty's portfolio. The student must produce an appropriate paper (e.g., conceptual or empirical) from this experience.
Units: 3

DEV 598: Graduate Qualifying Project

This three-credit graduate qualifying project, typically done in teams, is to be carried out in cooperation with a sponsor or external partner. It must be overseen by a faculty member affiliated with the Science, Technology, Innovation, and Global Development. This offering integrates theory and practice of design for science, engineering, and innovation, and should include the utilization of tools and techniques acquired in the program. In addition to a written report, this project must be presented in a formal presentation to the WPI community. Professional development skills, such as communication, teamwork, leadership, and collaboration, along with storytelling, will be practiced.
Units: 3
Prerequisites:
DEV 501, completion of at least 24 credits of the degree, or consent of the instructor

DEV 599: Masters Thesis

A thesis consists of a research and development project worth (a minimum of) nine graduate credit hours advised by a faculty member affiliated with the Program. A thesis proposal must be approved by the Science, Technology, Innovation, and Global Development Review Board and the student's advisors, before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the WPI community.
Units: 3

Electrical and Computer Engineering

CS 587/ECE 588: Cyber Security Capstone Experience

To reduce cyber security theory to practice, the capstone project has students apply security concepts to real-world problems. The capstone represents a substantial evaluation of the student's cyber security experience. Students are encouraged to select projects with practical experience relevant to their career goals and personal development. In the capstone, students will propose a project idea in writing with concrete milestones, receive feedback, and pursue the proposal objectives. Since cyber security is a collaborative discipline, students are encouraged to work in teams.

This course is a degree requirement for the Professional Master's in Cyber Security (PM-SEC) and may not be taken before completion of 21 credits in the program. Given its particular role, this course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. Students outside the PM-SEC program must get the instructor's approval before taking this course for credit.
Units: 3

CS 673/ECE 673: Advanced Cryptography

This course provides deeper insight into areas of cryptography which are of great practical and theoretical importance. The three areas treated are detailed analysis and the implementation of cryptoalgorithms, advanced protocols, and modern attacks against cryptographic schemes. The first part of the lecture focuses on public key algorithms, in particular ElGamal, elliptic curves and Diffie-Hellman key exchange. The underlying theory of Galois fields will be introduced. Implementation of performance security aspects of the algorithms will be looked at. The second part of the course deals with advanced protocols. New schemes for authentication, identification and zero-knowledge proof will be introduced. Some complex protocols for real-world application— such as key distribution in networks and for smart cards—will be introduced and analyzed. The third part will look into state-of-the-art cryptoanalysis (i.e., ways to break cryptosystems). Brute force attacks based on special purpose machines, the baby-step giant-step and the Pohlig-Hellman algorithms will be discussed.
Units: 3
Prerequisites:
CS 578/ ECE 578 or equivalent background

DS/ECE 577: Machine Learning in Cybersecurity

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.
Units: 3

ECE/DS 577: Machine Learning in Cybersecurity

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.
Units: 3

ECE 502: Analysis of Probabilistic Signals and Systems

Applications of probability theory and its engineering applications. Random variables, distribution and density functions. Functions of random variables, moments and characteristic functions. Sequences of random variables, stochastic convergence and the central limit theorem. Concept of a stochastic process, stationary processes and ergodicity. Correlation functions, spectral analysis and their application to linear systems. Mean square estimation.
Units: 3
Prerequisites:
Undergraduate course in signals and systems

ECE 503: Digital Signal Processing

Discrete-time signals and systems, frequency analysis, sampling of continuous time signals, the z-transform, implementation of discrete time systems, the discrete Fourier transform, fast Fourier transform algorithms, filter design techniques.
Units: 3
Prerequisites:
Courses in complex variables, basic signals and systems

ECE 504: Analysis of Deterministic Signals and Systems

Review of Fourier series and linear algebra. Fourier transforms, Laplace transforms, Z transforms and their interrelationship. State space modeling of continuous-time and discrete-time systems. Canonical forms, solution of state equations, controllability, observability and stability of linear systems. Pole placement via state feedback, observer design, Lyapunov stability analysis.
Units: 3
Prerequisites:
Undergraduate course in signals and systems

ECE 505: Computer Architecture

This course introduces the fundamentals of computer system architecture and organization. Topics include CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache and virtual memories, storage systems, standard local buses, high-performance I/O, computer communication, basic principles of operating systems, multiprogramming, multiprocessing, pipelining and memory management. The architecture principles underlying RISC and CISC processors are presented in detail. The course also includes a number of design projects, including simulating a target machine, architecture using a high-level language (HLL).
Units: 3
Prerequisites:
Undergraduate course in logic circuits and microprocessor system design, as well as proficiency in assembly language and a structured high-level language such as C or Pascal

ECE 506: Introduction to Local and Wide Area Networks

This course provides an introduction to the theory and practice of the design of computer communications networks according to IEEE 802 standard model for lower layers and IETF standard for TCP/IP higher layers. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types including local area and wide area networks are introduced, as are evolving network technologies. The theory, design and performance of local area networks are emphasized. The course includes application of queueing analysis to performance analysis of medium access control (MAC) and application of communication theory in design of physical layer (PHY).

Units: 3

Prerequisites:

familiarity to MATLAB programming is assumed. Background in undergraduate level courses in networking, probability, statistic, and signal processing

ECE 514: Fundamentals of RF and MW Engineering

This introductory course develops a comprehensive understanding of Maxwell's field theory as applied to high-frequency radiation, propagation and circuit phenomena. Topics include radiofrequency (RF) and microwave (MW) propagation modes, transmission line aspects, Smith Chart, scattering parameter analysis, microwave filters, matching networks, power flow relations, unilateral and bilateral amplifier designs, stability analysis, oscillators circuits, mixers and microwave antennas for wireless communication systems.

Units: 3

Prerequisites:

ECE 304 or equivalent, undergraduate course in electromagnetic field analysis

ECE 523: Power Electronics

The application of electronics to energy conversion and control. Electrical and thermal characteristics of power semiconductor devices—diodes, bipolar transistors and thyristors. Magnetic components. State-space averaging and sampled-data models. Emphasis is placed on circuit techniques. Application examples include dc-dc conversion, controlled rectifiers, high-frequency inverters, resonant converters and excitation of electric machines.

Units: 3

Prerequisites:

ECE 3204 and undergraduate courses in modern signal theory and control theory; ECE 304 is recommended

ECE 524: Advanced Analog Integrated Circuit Design

This course is an advanced introduction to the design of analog and mixed analog-digital integrated circuits for communication and instrumentation applications. An overview of bipolar and CMOS fabrication processes shows the differences between discrete and integrated circuit design. The bipolar and MOS transistors are reviewed with basic device physics and the development of circuit models in various operating regions. The use of SPICE simulation in the design process will be covered. Integrated amplifier circuits are developed with an emphasis on understanding performance advantages and limitation in such areas as speed, noise and power dissipation. Simple circuits are combined to form the basic functional building blocks such as the op-amp, comparator, voltage reference, etc. These circuit principles will be explored in an IC design project, which may be fabricated in a commercial analog process. Examples of possible topics include sample-and-hold (S/H) amplifier, analog-to-digital (A/D) and digital-to-analog (D/A) converters, phase-locked loop (PLL), voltage-controlled oscillator, phase detector, switched capacitor and continuous-time filters, and sampled current techniques.

Units: 3

Prerequisites:

Background in analog circuits both at the transistor and functional block [op-amp, comparator, etc.] level. Also familiarity with techniques such as small-signal modeling and analysis in the s-plane using Laplace transforms. Undergraduate course equivalent background ECE 3204; ECE 4902 helpful but not essential

ECE 529: Selected Topics in Electronic System Design

Courses in this group are devoted to the study of advanced topics in electronic system design.

Units: 3

ECE 530/CS 530: High Performance Networks

This course is an in-depth study of the theory, design and performance of high-speed networks. Topics include specific high-performance network architectures and protocols and emerging technologies including multimedia networks and quality-of-service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queueing models.

Units: 3

Prerequisites:

ECE 506/CS 513

ECE 531: Principles of Detection and Estimation Theory

Detection of signals in noise, optimum receiver principles, M-ary detection, matched filters, orthogonal signals and representations of random processes. MAP and maximum likelihood estimation. Wiener filtering and Kalman filtering. Channel considerations: prewhitening, fading and diversity combining.

Units: 3

Prerequisites:

ECE 502 and ECE 504 or equivalent

ECE 537/CS 577: Advanced Computer and Communications Networks

This course covers advanced topics in the theory, design and performance of computer and communication networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies.

Units: 3

Prerequisites:

ECE 506/CS 513 and ECE 581/CS 533

ECE 538: Wireless Technologies and Applications

A preview of evolution of wireless information networking standards and technologies for personal, local and six generations of cellular networks, and the distinct role of Wi-Fi in this evolution. Radio Frequency (RF) cloud from wireless devices and embedded big data in them. Models for the behavior of features of RF signals from wireless devices: the Received Signal Strength (RSS), Time-of- Arrival (TOA), Direction of Arrival (DOA), Channel Impulse Response (CIR), and Channel State Information (CSI). Application of models for features of RF signal for design and performance evaluation of mainstream wireless communication technologies: Spread Spectrum, Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input-Multiple-Output (MIMO) antenna systems, Ultra-Wideband (UWB) and millimeter wave (mmWave) technologies. RSS and TOA features of RF fingerprints of wireless devices for opportunistic positioning and tracking using Wi-Fi and cellular signals. Application of Artificial Intelligent (AI) algorithms and RSS, CIR, and CSI fingerprints of wireless devices to motion and gesture detection, as well as authentication and security. The course is complemented with practical MATLAB oriented assignments, and multi-media supplements. Students will prepare a term paper throughout the course on a topic negotiated with the instructor.

Units: 3

ECE 539: Selected Topics in Communication Theory and Signal Processing

Courses in this group are devoted to the study of advanced topics in in Communication Theory and Signal Processing.

Units: 3

ECE 545/CS 545: Digital Image Processing

See CS 545 course description.

Units: 3

ECE 549: Selected Topics in Control

Courses in this group are devoted to the study of advanced topics in the formulation and solution of theoretical or practical problems in modern control.

Units: 3

ECE 559: Selected Topics in Energy Systems

Courses in this group are devoted to the study of advanced topics in energy systems. Typical topics include optimal power flow, probability methods in power systems analysis, surge phenomena, design of electrical apparatus, transient behavior of electric machines and advanced electromechanical energy conversion.

Units: 3

ECE 566: VLSI Design

VLSI Design introduces computer engineers and computer scientists to the techniques, methodologies and issues involved in conceptual and physical design of complex digital integrated circuits. The course presupposes knowledge of computer systems and hardware design such as found in ECE 505, but does not assume detailed knowledge of transistor circuits and physical electronics.

Units: 3

Prerequisites:

ECE 505 or equivalent

ECE 569: Selected Topics in Solid State

Courses in this group are devoted to the study of advanced topics in solid state, for example: degenerate semiconductors, many-body theory, elastic effects and phonon conduction, and solar cells. To reflect changes in faculty research interests, these courses may be modified or new courses may be added.

Units: 3

ECE 572/CS 514: Advanced Systems Architecture

This course covers techniques such as caching, hierarchical memory, pipelining and parallelism, that are used to enhance the performance of computer systems. It compares and contrasts different approaches to achieving high performance in machines ranging from advanced microprocessors to vector supercomputers (CRAY, CYBER). It also illustrates how these techniques are applied in massively parallel SIMD machines (DAP, Connection Machine). In each case the focus is on the combined hardware/software performance achieved and the interaction between application demands and hardware/software capabilities.

Units: 3

Prerequisites:

This course assumes the material covered in ECE 505. The student should also have a background in computer programming and operating systems (CS 502). Familiarity with basic probability and statistics such as ECE 502 or MA 541 is recommended

ECE 574: Modeling and Synthesis of Digital Systems Using Verilog and Vhdl

This is an introductory course on Verilog and VHDL, two standard hardware description languages (HDLs), for students with no background or prior experience with HDLs. In this course we will examine some of the important features of Verilog and VHDL. The course will enable students to design, simulate, model and synthesize digital designs. The dataflow, structural, and behavioral modeling techniques will be discussed and related to how they are used to design combinational and sequential circuits. The use of test benches to exercise and verify the correctness of hardware models will also be described. Course Projects: Course projects will involve the modeling and sysntesis and testing of systems using Xilinx tools. We will be targeting Xilinx FPGA and CPLDs. Students will need to purchase a FPGA or CPLD development board for project assignments. (Other VHDL tools may be used if these are available to the student at their place of employment.) Students will have the choice of completing assignments in either Verilog or VHDL. Students cannot receive credit for both ECE 574 and ECE 5720

Units: 3

Prerequisites:

Logic Circuits and experience with programming in a high-level language (such as C or Pascal) and a computer architecture course such as ECE 505.)

ECE 578/CS 578: Cryptography and Data Security

This course gives a comprehensive introduction to the field of cryptography and data security. The course begins with the introduction of the concepts of data security, where classical algorithms serve as an example. Different attacks on cryptographic systems are classified. Some pseudo-random generators are introduced. The concepts of public and private key cryptography are developed. As important representatives for secret key schemes, DES and IDEA are described. The public key schemes RSA and ElGamal, and systems based on elliptic curves are then developed. Signature algorithms, hash functions, key distribution and identification schemes are treated as advanced topics. Some advanced mathematical algorithms for attacking cryptographic schemes are discussed. Application examples will include a protocol for security in a LAN and a secure smart card system for electronic banking. Special consideration will be given to schemes which are relevant for network environments. For all schemes, implementation aspects and up-to-date security estimations will be discussed.

Units: 3

Prerequisites:

Working knowledge of C; an interest in discrete mathematics and algorithms is highly desirable. Students interested in a further study of the underlying mathematics may register for MA 4891 [B term], where topics in modern algebra relevant to cryptography will be treated

ECE 579: Selected Topics in Computer Engineering

Courses in this group are devoted to the study of advanced topics in computer engineering such as real-time intelligent systems, VLSI design and high-level languages.

Units: 3

ECE 581/CS 533: Modeling and Performance Evaluation of Network and Computer Systems

Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; work load characterization; performance evaluation problems.

Units: 3

Prerequisites:

CS 504 or ECE 502, or equivalent background in probability

ECE 588/CS 587: Cyber Security Capstone Experience

To reduce cyber security theory to practice, the capstone project has students apply security concepts to real-world problems. The capstone represents a substantial evaluation of the student's cyber security experience. Students are encouraged to select projects with practical experience relevant to their career goals and personal development. In the capstone, students will propose a project idea in writing with concrete milestones, receive feedback, and pursue the proposal objectives. Since cyber security is a collaborative discipline, students are encouraged to work in teams.

This course is a degree requirement for the Professional Master's in Cyber Security (PM-SEC) and may not be taken before completion of 21 credits in the program. Given its particular role, this course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. Students outside the PM-SEC program must get the instructor's approval before taking this course for credit.

Units: 3

ECE 596A and ECE 596B: Graduate Seminars

The presentations in the graduate seminar series will be of tutorial nature and will be presented by recognized experts in various fields of electrical and computer engineering. All full-time graduate students will be required to take both seminar courses, ECE 596A and ECE 596B, once during their graduate studies in the Electrical and Computer Engineering Department. The course will be given Pass/Fail.

Units: 3

Prerequisites:

Graduate standing

ECE 597: Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Can be technical in nature, or a review of electrical and computer engineering history and literature of importance and permanent value.

Units: 3

Prerequisites:

B.S. in ECE or equivalent

ECE 598: Directed Research

Each student will work under the direct supervision of a member of the department staff on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required. (A maximum of two registrations in ECE 598 is permitted

Units: 3

Prerequisites:

Graduate standing

ECE 599: Thesis

Units: 3

ECE 630: Advanced Topics in Signal Processing

The course will cover a set of important topics in signal and image analysis: orthogonal signal decomposition, wavelet transforms, analytic signals, time-frequency estimation, 2D FT, Hankel transform and tomographic reconstruction. In addition, the course will each year have selected current topics in signal processing, e.g., ambiguity functions in RADAR and SONAR, coded waveforms, Fourier based beamforming for 2D arrays and single value decomposition. In place of a final exam, there will be a student project. The course is intended for students working in areas such as image analysis, NDE, ultrasound, audio, speech, RADAR, SONAR and date compression. Signal/ image theory and applications will be emphasized over coding; however, Matlab-based modules for self-paced signal/image visualization and manipulation will be part of the course.

Units: 3

Prerequisites:

ECE 504 Analysis of Deterministic Signals and Systems, undergraduate course in linear systems theory and vector calculus

ECE 699: Ph.D. Dissertation

Units: 3

ECE 5105: Introduction to Antenna Design

This course is intended for graduate and senior-level undergraduate students. The course provides an introduction to major antennas and antenna types for wireless communications. Basic antenna characteristics are studied. Both narrowband and broadband antennas as well as antenna arrays are considered. One emphasis is made on learning antenna modeling software, ANSYS HFSS and Antenna Toolbox of MATLAB. Another emphasis is made on the basic measurement hardware. The course structure is directed toward understanding antenna operations and basic antenna design, and enables students with a broad background to take this course. Course topics in particular include: transmitter-receiver antenna circuit models, antenna radiation and radiation parameters, dipole antenna family, patch antenna family, loop antenna family, reflector antennas, small antennas, antenna matching and tuning, antenna arrays, on-body and in-body antennas, antenna measurements and modeling.

Units: 3

Prerequisites:

undergraduate analog electronics, college MATLAB, and basic introductory knowledge of electromagnetic theory -ECE 2019 and ECE 3113

ECE 5106: Modeling of Electromagnetic Fields in Electrical & Biological Systems

This course is intended for graduate and senior-level undergraduate students. Modern numerical methods and major software packages are reviewed in application to modeling electrical and biomedical sensors, bioelectromagnetics, wireless communications (including wireless body area networks), and power electronics. The course begins with an introduction to computational mesh generation. Triangular surface meshes, volumetric tetrahedral meshes, voxel meshes, and computational human phantoms are studied. The boundary element method or the method-of-moments is introduced and detailed, followed by a review of the finite element method for electromagnetic problems. The finite-difference time-domain method is another major topic of the course. The course also covers ray tracing algorithms in application to wireless networks.

Units: 3

Prerequisites:

college MATLAB, differential and integral calculus

ECE 5204: Analog Circuits and Intuition

The ability to see the simplicity in a complex design problem is a skill that is not usually taught in engineering classes. Some engineers, when faced with design problems, immediately fill up pages and pages of calculations, or do complex circuit simulations or finite-element analyses. One problem with this approach is that if you get an answer, you do not know if it is correct unless you have an intuitive “feel” for what the answer should be. The application of some simple rules of thumb and design techniques is a possible first step to developing intuition into the behavior of complex electrical systems. This course outlines some ways of thinking about analog circuits and systems that are intended will help to develop intuition and guide design. The lectures are a mixture of instructional sessions covering new background material, and design case studies.

Units: 3

Prerequisites:

Undergraduate background in device physics, microelectronics, control systems, electromagnetism

ECE 5307: Wireless Access and Localization

This course covers the fundamentals of the evolving wireless localization techniques and their relation with the wireless access infrastructures for Electrical and Computer Engineering, Computer Science or other graduate students interested in this field. The course begins with an explanation of the common ground among wireless access and localization techniques which are principles of waveform transmission in multipath rich urban and indoor areas and the deployment of the infrastructure for wireless networks. This is followed by the fundamentals of received signal strength (RSS) and Time- and Angle-of-arrival (TOA/ AOA) based localization techniques, addressing applications, systems, effects of environment, performance bounds and algorithms. The course describes how wireless access methods used in wide, local and personal area networks are related to localization techniques using cellular, UWB, WiFi, and other signals of opportunity as well as mechanical sensors used in different smart phone and Robotic platforms. The emphasis on the effects of environment is on the analysis of the effects of multipath on precision of the localization techniques. The emphasis on performance evaluation is on the derivation of Cramer Rao Lower Bound (CRLB). For algorithms, the course describes fingerprinting algorithms used for RSS-based localization and super-resolution, cooperative localization, localization using multi-carrier transmission and localization using multipath diversity as well as Kalman and Particle filtering techniques used for model based localization. Examples of emerging technologies in Body Area Networking and Robotics applications are provided.
Units: 3
Prerequisites:
ECE 506, CS 513, or equivalent familiarity with local and wide area networks

ECE 5311: Information Theory and Coding

This course introduces the fundamentals of information theory and discusses applications in compression and transmission of data. Measures of information, including entropy, and their properties are derived. The limits of lossless data compression are derived and practical coding schemes approaching the theoretical limits are presented. Lossy data compression tradeoffs are discussed in terms of the rate-distortion framework. The concept of reliable communication through noisy channels (channel capacity) is developed. Techniques for practical channel coding, including block and convolutional codes, are also covered.
Units: 3
Prerequisites:
background in probability and random processes such as in ECE502 or equivalent

ECE 5312: Modern Digital Communications

This course introduces a rigorous analytical treatment of modern digital communication systems, including digital modulation, demodulation, and optimal receiver design. Error performance analysis of these communication systems when operating over either noisy or band-limited channels will be conducted. Advanced topics to be covered include a subset of the following: MIMO, fading channels, multiuser communications, spread spectrum systems, and/or multicarrier transmission.
Units: 3
Prerequisites:
An understanding of probability and random processes theory (ECE 502 or equivalent); an understanding of various analog and digital (de) modulation techniques (ECE 3311 or equivalent); familiarity with MAT-LAB programming.

ECE 5341: Applied Medical Signal Analysis

This course provides a broad introduction to medical signal analysis, particularly tailored to students who have no prior background in physiology or medicine. The course will concentrate on signal analysis of the electrical activity of the human body, providing sufficient physiologic background for study of the relevant organ systems. System-level engineering models of the electrical activity of the heart, skeletal muscles and brain will be presented and actual physiologic signals will be analyzed. Digital signal processing algorithms for analysis of these signals will be studied extensively using MATLAB. Specific signal processing topics may include: use of muscle electrical activity to command powered prostheses and/ or guide rehabilitation therapy; design of filters to reject motion artifact, noise and interference; monitoring (e.g., detection and classification) of heart, brain and muscle electrical impulses; and non-invasive estimation of muscle activation level. Students may not receive credit for ECE 5341 and either ECE 443X or ECE 539D.
Units: 3
Prerequisites:
Undergraduate (or graduate) course in digital signal processing, experience with MATLAB and a course in probability

ECE 5500: Power System Analysis

This graduate level course examines the principles of Power System Analysis. It will begin with a review of AC circuit analysis. The course will then cover the topics of transmission line parameter calculation, symmetrical component analysis, transformer and load modeling, symmetrical and unsymmetrical fault analysis, power flow, and power systems stability.
Units: 3
Prerequisites:
Knowledge of circuit analysis, basic calculus and differential equations, elementary matrix analysis and basic computer programming

ECE 5510: Power Quality

This graduate level course provides detailed explanations of the physical mechanisms that control phenomena related to Power Quality. It addresses concepts that underlie harmonic generation and harmonic flow, and the modeling of voltage sags and swells. The effects of such disturbances on equipment (transformers, rotating machines, lamps, relays and converters) performance are studied by means of actual field cases. Frequency response of the grid, resonances and ferroreso-nances as well as electromagnetic interference are studied. Mitigation methods using advanced transformers connections, static, hybrid and active filters are modeled using real-life examples. Others topics covered are Power Quality measurements in the era of smart grid, Power Quality problems caused by Renewable Generators, and Engineering Economics issues related to Power Quality.
Units: 3
Prerequisites:
ECE 5500 Power System Analysis. Also, this course presumes that the student has an understanding of basic electronics

ECE 5511: Transients in Power Systems

This graduate level course introduces the student to the effects of electromagnetic transients in distribution systems. Topics include transient analysis, lightning and switching surges, mechanisms of transient generation, insulation coordination, grounding, surge protection devices, and shielding.
Units: 3
Prerequisites:
ECE 5500 Power System Analysis

ECE 5512: Electromechanical Energy Conversion

This graduate level course will further explore alternating current circuits, three phase circuits, basics of electromagnetic field theory, magnetic circuits, inductance, and electromechanical energy conversion. Topics also include ideal transformer, iron-core transformer, voltage regulation, efficiency equivalent circuit, and three phase transformers. Induction machine construction, equivalent circuit, torque speed characteristics, and single phase motors, synchronous machine construction, equivalent circuit, power relationships phasor diagrams, and synchronous motors will be covered. Direct current machine construction, types, efficiency, power flow diagram, and external characteristics will be discussed.
Units: 3

ECE 5520: Power System Protection and Control

This graduate level course seeks to provide an understanding of how interconnected power systems and their components are protected from abnormal events such as faults (short circuits), over-voltages, off-nominal frequency and unbalanced phase conditions. This subject is presented from a theoretical viewpoint, however, many practical examples and applications are included that emphasize the limitations of existing protective equipment. Course content is not specific to any particular manufacturer's equipment. The course begins with a brief review of power system operation, three-phase system calculations and the representation (modeling) of power system elements. The modeling of current transformers under steady-state and transient conditions is presented with emphasis on the impact on protective devices. A unit on system grounding and its impact on protective device operation are included. Course emphasis then shifts to protective devices and their principles of operation. Both electromechanical and numeric relay designs are covered. The final course segments cover specific applications such as pilot protection of transmission lines, generator protection and transformer protection.

Units: 3

Prerequisites:

ECE 5500 Power System Analysis

ECE 5521: Protective Relaying

This graduate level course is the first of a two course sequence that covers both the principles and practices of power system protective relaying. The course seeks to provide an understanding of how interconnected power systems and their components are protected from abnormal events such as faults (short circuits), over-voltages, off-nominal frequency and unbalanced phase conditions. This subject is presented from a theoretical viewpoint, however, many practical examples are included that emphasize the limitations of existing protective equipment. Course content is not specific to any particular manufacturers equipment. The course begins with a brief review of the nature of power system operation, power system faults and other abnormal conditions. The nature and objectives of protective relaying are covered next with emphasis on how the power system can be monitored to detect abnormal conditions. The computational tools needed to analyze system operation and apply protective relaying are covered next, including the per-unit system, phasors and symmetrical components. The modeling of current transformers under steady-state and transient conditions is presented with emphasis on the impact on protective devices. A unit on system grounding and its impact on protective device operation is included. Course emphasis then shifts to protective devices and their principles of operation. Both electromechanical and numeric relay designs are covered. Note: Credit cannot be awarded for this course if credit has already been received for ECE 5520 Power System Protection and Control

Units: 3

Prerequisites:

ECE 5500 Power System Analysis or equivalent background experience is suggested. Familiarity with phasors, derivatives, transfer functions, poles and zeros, block diagram and the notion of feedback with basic understanding power system analysis or similar background is recommended.

ECE 5522: Advanced Applications in Protective Relaying

This graduate level course covers advanced topics in the principles and practices of power system protective relaying. The course seeks to provide an understanding of how protective relays are applied to protect power system components. While the subject is presented from a theoretical viewpoint, many practical examples are included. Examples specific to both new installations and existing, older facilities will be included. Course content is not specific to any particular manufacturers equipment. The course begins with applications of protective devices to generators. This will include distributed generation as well as wind-turbine and inverter-connected sources. Transformer protection is covered next, including application procedures for older, electromechanical relays as well as modern numeric relay designs. A unit on bus protection is covered next, including all typical high-speed and time backup bus protection schemes. Transmission line and distribution feeder protection is covered in detail including both conventional and communications-assisted schemes. The course ends with a unit on other protection applications such as under frequency load shedding, reclosing and out-of-step relaying. Note: Credit cannot be awarded for this course if credit has already been received for ECE 5520 Power System Protection and Control

Units: 3

Prerequisites:

ECE 5521 Protective Relaying.

ECE 5523: Power System Dynamics

This graduate level course is concerned with modeling, analyzing and mitigating power system stability and control problems. The course seeks to provide an understanding of the electromechanical dynamics of the interconnected electric power grid. This subject is presented from a theoretical viewpoint; however, many practical examples are included. The course begins with a description of the physics of the power system, frequency regulation during “steady-state” operation, dynamic characteristics of modern power systems, a review of feedback control systems, power system frequency regulation, and a review of protective relaying. This is followed by material on synchronous machine theory and modeling. Simulation of power system dynamic response, small signal stability, transient stability analysis using SIMULINK and effects of non-traditional power sources on systems dynamics will also be covered. Power system stabilizers, load modeling and under frequency load shedding are covered in the final lectures.

Units: 3

Prerequisites:

ECE 5500 Power System Analysis and ECE 5511 Transients in Power Systems or equivalent background experience is suggested. Familiarity with the basics of Laplace Transforms, derivatives, transfer functions, poles and zeros, block diagram and the notion of feedback with basic understanding power system analysis topics recommended

ECE 5530: Power Distribution

This graduate level course introduces the fundamentals of power distribution systems, apparatus, and practices suited to new and experienced utility distribution engineers. Topics include distribution system designs, transformers and connections, practical aspects of apparatus and protection, principles of device coordination, grounding, voltage control, and power quality.

Units: 3

Prerequisites:

Prior courses in magnetism and three-phase circuits. An electric machines course would be recommended

ECE 5531: Power System Operation and Planning

This graduate-level course deals with modern operation, control and planning for power systems. Topics include: Characteristics of generating units; Economic Dispatch; Unit Commitment; Effects of the transmission system on power delivery; Optimal Power Flow and Location Marginal Pricing; Power System Security; State Estimation for Power Systems; Power System Reliability Evaluation. Software tools such as MATLAB and power system simulator software will be used both in the classroom and in some homework assignments.

Units: 3

ECE 5532: Distributed and Renewable Power Generation

This course introduces the characteristics and challenges of interconnecting increasing numbers of Distributed Energy Resources (DERs) to the Electric Power System (EPS). Topics include: challenges to distribution and transmission system protection; local voltage control; ride through; optimal interconnection transformer configurations; and practical engineering approaches to maintain system reliability and protection. The current and evolving interconnection standard (IEEE 1547) is included.

Units: 3

Prerequisites:

Since the course material builds on power system analysis capabilities, including system protection and controls, ECE 5500 Power System Analysis and either ECE 5520 Power System Protection & Control or ECE 5521 Protective Relaying are required. Also, it is recommended that students take this course after completing ECE 5530 Power Distribution.

ECE 5540: Power Transmission

This graduate level course focuses on the theory and current professional practice in problems of electric power transmission. It begins with a review of the theory of AC electric power transmission networks and addresses a range of challenges related to reactive power and voltage control as well as steady-state and transients stability. Students will learn in detail the principles of traditional reactive power compensation (shunt reactors and capacitors); series compensation and modern static reactive compensation like SVC, STATCOM and other Flexible AC Transmission Systems (FACTS) devices. The effects of each of these types of compensation on static and dynamic voltage control, reactive power requirement and steady-state and transient stability problems are covered from theoretical as well as practical aspects. Particular attention is given to the mathematical models and principles of operation of many types of compensation systems. Basic principles of operation and control of High-Voltage DC (HVDC) systems and their impact on steady-state and dynamics of power system will be covered as well.

Units: 3

Prerequisites:

ECE 5500 Power System Analysis

ECE 5599: Capstone Project Experience in Power Systems

This project-based course integrates power systems engineering theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Power Systems curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Power Systems profession.

Units: 3

Prerequisites:

Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the capstone project

ECE 5715: Reconfigurable Computing

This course focused on the principles and applications of using FPGAs for reconfigurable computing. The key feature of reconfigurable computing is its ability to perform computations in customized hardware, while retaining much of the flexibility of a software solution. This course provides an overview of field programmable gate array (FPGA) architecture and technology. It introduces computer-aided design tools for FPGAs including synthesis, timing, placement, and routing. The course emphasizes on the techniques to analyze algorithms and to implement them on the FPGAs. It demonstrates real-time signal and data processing in customized hardware circuits. This course also covers system-on-chip design using the embedded processors inside the FPGAs. Partially reconfiguration and runtime reconfiguration design flow are also included.

Units: 3

ECE 5720: Modeling and Synthesis of Digital Systems Using Verilog

Automatic design, synthesis, verification, and modeling of complex digital systems with Verilog are the main course objectives. Verilog for modeling existing circuits, as well as Verilog for design and automatic synthesis is discussed. Using Verilog for a design that consists of a hierarchy of components that include controllers, sequential and combinational parts is focused. Design description from transistor level to software interface will be discussed. Students will learn details of hardware of processor architectures and their peripherals. The course discusses module delay adjustments using Verilog path delay and distributed delay mechanisms. Testbench development and assertion verifications will be discussed. Students will learn to simulate verify, synthesize, and program their designs on an Altera development board using advanced Altera FPGAs.

Units: 3

Prerequisites:

Undergraduate knowledge of basic logic design concepts. ECE 574 may be substituted for ECE 5720. Students may not receive credit for both ECE 574 and ECE 5720). For students not having the necessary background, online videos will be made available to cover the prerequisites.

ECE 5722: Embedded Core Architectures and Core-Based Design

This course introduces the concept of design with embedded components. Embedded processors, IP cores, and bus structures are discussed here. Embedded processor architectures, architectures for arithmetic processors, I/O interfacing modules, memory interfacing, and architectures related to busses and switch fabrics for putting a complete embedded system are discussed here. Topics include RT level design, arithmetic processors, ISA, CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache, standard local buses, IO devices, pipelining, memory management, embedded processors, embedded environments, bus and switch fabrics, and embedded system implementation. An example embedded design environment including its configurable cores and processors and its bus structure will be presented in details. The course also includes a number of design projects, including design and simulation of an embedded processor, design of an arithmetic core, and design of a complete embedded system.

Units: 3

Prerequisites:

Familiarity with C programming, Undergraduate knowledge of basic logic design concepts, familiarity with a hardware description language). Note: For students not having the necessary background, online videos will be made available to cover the prerequisites.

ECE 5723: Methodologies for System Level Design and Modeling

This course discusses principles, methodologies and tools used for a modern hardware design process. Design flows and hardware languages needed for each stage of the design process are discussed. The use of transaction level modeling (TLM) for dealing with todays complex designs is emphasized. The course starts with a discussion of the evolution of hardware design methodologies, and then discusses the use of C++ for an algorithmic description of hardware. SystemC and its TLM derivative and the role of SystemC in high-level design will be discussed. In addition, RT level interfaces and the use of SystemC for this level of design will be covered. Timed, untimed, and approximately timed TLM models and modeling schemes will be presented. Use of TLM for fast design simulation, design space exploration, and high-level synthesis will be discussed. TLM testing methods and testing of TLM based NoCs will be discussed. The course starts with a complete design project and exercises various parts of this design as methodologies, concepts, and languages are discussed. Specific topics covered are as follows: Levels of abstraction C++ for digital design SystemC RT level and above TLM methodology TLM timing aspects TLM channels TLM channels Mixed level design NoC TLM modeling System testing

Units: 3

ECE 5724: Digital Systems Testing and Testable Design

This course discusses faults and fault modeling, test equipment, test generation for combinational and sequential circuits, fault simulation, memory testing, design for testability, built-in self-test techniques, boundary scan, IEEE 1149.1, and board and SoC test standards. Various fault simulation and ATPG methods including concurrent fault simulation, D-algorithm, and PODEM are discussed. Controllability and observability methods such as SCOAP for testability analysis are discussed. Various full-scan and partial scan methods are described and modeled in Verilog and tested with Verilog testbenches. BIST architectures for processor testing, memory testing and general RT level hardware testing are described, modeled in Verilog and simulated and evaluated for fault coverage. The course uses Verilog testbenches for simulating golden models, developing and evaluating test sets, and for mimicking testers.
Units: 3
Prerequisites:
Understanding digital systems and design of combinational and sequential circuits, Understanding a hardware description language (VHDL or Verilog) and the use of these languages for simulation and synthesis

ECE 5905: Advanced Bipolar Solid State Devices

The operation of the bipolar junction transistor (BJT) will be explored in detail, resulting in thorough understanding of observed phenomena including second-order effects that limit device performance in practical integrated circuit applications. The course begins with a review of semiconductor fundamentals and p-n junction behavior, followed by extension to the BJT, with an emphasis on effects such as temperature dependence of operation parameters, deviations from ideal behavior at high and low voltages and currents, and failure modes such as zener and avalanche breakdown. BJT behavior will be modeled for large and small signals under DC, AC, and transient conditions. Results from theoretical hand-analysis equations will be correlated with model parameters in software tools such as SPICE. Implications of fabrication technology including device scaling in submicron processes will be considered. This course is intended for students pursuing study in either integrated circuit design or device physics.
Units: 3
Prerequisites:
undergraduate analog electronics

Fire Protection Engineering

FP 520: Fire Modeling

Modeling of compartment fire behavior is studied through the use and application of two types of models: zone and field. The zone model studied is a student developed model. The field model studied is FDS. Focus on in-depth understanding of each of these models is the primary objective in terms of needed input, equations solved, interpretation of output and limitations. A working student model is required for successful completion of the course. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study.
Units: 3
Prerequisites:
FP 521 or permission of the instructor

FP 521: Fire Dynamics I

This course introduces students to fundamentals of fire and combustion and is intended to serve as the first exposure to fire dynamics phenomena. The course includes fundamental topics in fire and combustion such as thermodynamics of combustion, fire chemistry, premixed and diffusion flames, solid burning, ignition, plumes, heat release rate curves, and flame spread. These topics are then used to develop the basis for introducing compartment fire behavior, pre- and post-flashover conditions and zone modeling. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study.
Units: 3
Prerequisites:
Undergraduate chemistry, thermodynamics or physical chemistry, fluid mechanics and heat transfer

FP 553: Fire Protection Systems

This course provides an introduction to automatically activated fire suppression and detection systems. A general overview is presented of relevant physical and chemical phenomena, and commonly used hardware in automatic sprinkler, gaseous agent, foam and dry chemical systems. Typical contemporary installations and current installation and approval standards are reviewed.

Units: 3

Prerequisites:

Undergraduate courses in chemistry, fluid mechanics and either thermodynamics or physical chemistry

FP 554: Advanced Fire Suppression

Advanced topics in suppression systems analysis and design are discussed with an aim toward developing a performance-based understanding of suppression technology. Automatic sprinkler systems are covered from the standpoint of predicting actuation times, reviewing numerical methods for hydraulic analyses of pipe flow networks and understanding the phenomenology involved in water spray suppression. Special suppression systems are covered from the standpoint of two-phase and non-Newtonian pipe flow and simulations of suppression agent discharge and mixing in an enclosure.

Units: 3

FP 555: Detection, Alarm and Smoke Control

Principles of fire detection using flame, heat and smoke detector technology are described. Fire alarm technology and the electrical interface with fire/smoke detectors are reviewed in the context of contemporary equipment and installation standards. Smoke control systems based on buoyancy and HVAC principles are studied in the context of building smoke control for survivability and safe egress.

Units: 3

FP 570: Building Fire Safety I

This course focuses on the presentation of qualitative and quantitative means for firesafety analysis in buildings. Fire test methods, fire and building codes and standards of practice are reviewed in the context of a systematic review of firesafety in proposed and existing structures.

Units: 3

FP 571: Performance-Based Design

This course covers practical applications of fire protection engineering principles to the design of buildings. Both compartmented and non-compartmented buildings will be designed for criteria of life safety, property protection, continuity of operations, operational management and cost. Modern analytical tools as well as traditional codes and standards are utilized. Interaction with architects and code officials, and an awareness of other factors in the building design process are incorporated through design exercises and a design studio.

Units: 3

Prerequisites:

FP 553, FP 521 and FP 570, or special permission of the instructor

FP 572: Failure Analysis

Development of fire investigation and reconstruction as a basis for evaluating and improving fire-safety design. Accident investigation theory and failure analysis techniques such as fault trees and event sequences are presented. Fire dynamics and computer modeling are applied to assess possible fire scenarios and the effectiveness of fire protection measures. The product liability aspects of failure analysis are presented. Topics include products liability law, use of standard test methods, warnings and safe product design. Application of course materials is developed through projects involving actual case studies.

Units: 3

FP 573: Industrial Fire Protection

Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyze fire protection requirements for generic industrial hazards. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage, and flammable liquid processing and storage. Historic industrial fires influencing current practice on these topics are also discussed.

Units: 3

Prerequisites:

FP 553, FP 521 or special permission of the instructor

FP 575: Explosion Protection

Principles of combustion explosions are taught along with explosion hazard and protection applications. Topics include a review of flammability limit concentrations for flammable gases and dusts; thermochemical equilibrium calculations of adiabatic closed-vessel deflagration pressures, and detonation pressures and velocities; pressure development as a function of time for closed vessels and vented enclosures; the current status of explosion suppression technology; and vapor cloud explosion hazards.
Units: 3

FP 580: Special Problems

Individual or group studies on any topic relating to fire protection may be selected by the student and approved by the faculty member who supervises the work. Examples include: • Business Practices • Combustion • People in Fires • Fire Dynamics II • Fire and Materials • Forensic Techniques • Complex Decision Making
Units: 3

FP 590: Thesis

Research study at the M.S. level.
Units: 3

FP 690: Ph.D. Dissertation

Units: 3

General Social Science

SS 590: Special Topics in Social Science and Policy Studies

Individual or group studies on any topic relating to social science and policy studies selected by the student and approved by the faculty member who supervises the work.
Units: 1
Prerequisites:
permission of the instructor.

Interactive Media & Game Development

IMGD 699: Phd Dissertation

Can be taken any time after passing the qualifying exam, and is required in the last semester for writing and defending the PhD dissertation.
Units: 0
Prerequisites:
Consent of advisor

IMGD 799: Ph.D. Qualifying Examination.

Students are required to complete a qualifying examination process before work can begin on PhD thesis research. This examination must be approved by a committee of faculty.
Units: 0

IMGD 5000: IMGD Studio

This is a “studio” course in which the instructor will guide and mentor the students on individual and/or joint projects. The focus of the course will be on the design of interactive media and games, with the students designing (and optionally implementing) one or more games or interactive experiences. There will also be readings and discussion of design theory as it relates to student projects. This course can be taken for M.S. credit twice if desired.
Units: 3

IMGD 5010: IMGD Fundamentals

In this course, students learn foundational theories and gain foundational skills in interactive media, game development, and computational media targeted at the graduate level, for students with a prior undergraduate background in related fields. Students will read about contemporary challenges in application of these fundamentals to IMGD-related projects, and build disciplinary knowledge and practices necessary for the creation of interactive media and/or games. Topics covered in this course alternate each year based on instructor. Different instantiations of the course cover topics in programming and computing in media contexts (computation studio), art asset conceptualization, creation, and iteration (visual arts studio), audio remixing and composition methods (audio lab), and narrative in interactive contexts (narrative design lab). This course will be offered each year, with topic defined by the faculty member teaching it.
Units: 3

IMGD 5099: Special Topics in IMGD

Units: 3

IMGD 5100: Tangible and Embodied Interaction

Tangible and embodied interaction sees humans at the center of the designed experience. A number of systems continue to emerge to immerse the body into a system, such as virtual reality, augmented reality, mixed reality, alternative controls in the forms of guitars or cockpits, sewing machines, mobile phones and technologies, and even more. Through a combination of traditional lecture, literature review, and hands-on work, students will learn to critically evaluate different alternatives, build prototype systems, and design comparative evaluations to test the effectiveness of various techniques. Students will be expected to implement several techniques as part of this course.

Units: 3

IMGD 5200: History and Future of Immersive and Interactive Media

This course will familiarize students with the history of the development, deployment, commercialization, and evolution of immersive and active media. The lesson plan will cover a broad range of enabling technologies, such as geometric perspective drawing, pre-20th-century panoramic displays, photography and the stereoscope, sound recording and reproduction, motion pictures, radio and television, the planetarium, immersive and 3-dimensional cinema, and special attraction venues, with a particular focus on digital games. Current trends and future directions will also be considered. Students will attend seminars and lectures, read and discuss texts on media history and aesthetics, and write an original research paper. Midterm and final exams test students' knowledge and understanding of important events and developments. A student may not receive credit for both IMGD 3200 and IMGD 4200.

Units: 3

Prerequisites:

An understanding of dominant themes and genres in video games

IMGD 5300: Design of Interactive Experiences

This course will introduce students to the theories of design, the purpose of which is to guide students in articulating a design vision that can then be implemented in an interactive experience such as a computer game or an art installation. The design elements addressed in this course are as follows: narrative, visual, sound, spatial, challenges and objectives, and characters. This course also emphasizes the communicative strategies needed to sell other people on a design in order to enter production, convince investors, and engage users. Students will be required to design an environment that is populated in a meaningful way that is dependant on the purpose of their visions. They will provide mock-ups of this environment that they must present to their stakeholders - the professor and peers - and finally create prototypes that help them sell their design idea. Throughout the class, students will be writing their designs in professional genres, presenting their designs to the class (often called a pitch), and discuss the theories and practices of design during in-class meetings.

Units: 3

Prerequisites:

A course on game design, or equivalent work experience

IMGD 5400: Production Management for Interactive Media

This course focuses on the process of creating a set of documents encompassing the design and vision of a piece of interactive media, methods for structuring the implementation of the design, and tools for successfully managing the project. Students will analyze different types of design documents, focusing on form and purpose while also considering audience and publication medium. Students will write design documents, give peer feedback, and revise their own documents based on feedback received. In order to see their design transform from document to product, students will study different project management methods and employ them, defining in detail discrete components, timelines, milestones, players and their responsibilities, and status reports to stakeholders. Tools common to managing interactive media projects (e.g., source-code revision control, asset management, scheduling) will be used throughout the process.
Units: 3
Prerequisites:
Experience working on development projects

IMGD 5500: Serious and Applied Games

This course covers methods and analysis for designing, implementing, and assessing games in serious, applied contexts. Often called "serious games" or "applied games", these are game-based media that teach, engage with social issues, aim to increase empathy, or affect behavioral change. Students will read contemporary literature in the field of serious and applied games, design and implement their own games, and measure the effectiveness of those games in achieving educational or motivational goals.
Units: 3

IMGD 5600: Multidisciplinary Research Methods in Computational Media

This course covers research methods used in computational and interactive media. As an interdisciplinary field, computational media relies on multiple research methods, such as qualitative, quantitative, design-based research, iterative design methodology, player and user-testing, historical and cultural research methods, computational reasoning, data analysis, and visual analysis. Students will read broadly in research methodologies and discuss applicability and adaptability for particular processes and research questions.
Units: 3

IMGD 6000: IMGD Colloquium

This course introduces students to the state of the field and current research in the program. Both faculty and external visitors to IMGD will speak at the colloquia on contemporary and emergent topics in interactive media and game design. This course is taken with a pass/fail grading option.
Units: 1

IMGD 6001: IMGD Career Colloquium

This course meets weekly to professionalize students preparing for the academic or artistic job markets. Topics will include goal setting, application materials, practice interviews, practice teaching demonstrations, portfolio development, and other materials as needed. This course is taken with a pass/fail grading option.
Units: 1

Interdisciplinary Programs

ID 500: Responsible Conduct of Research

The purpose of this zero credit course is to familiarize pre-doctoral and postdoctoral trainees with basic ethical issues in research confronting scientists and engineers. The course includes lectures and student-led discussion sessions on topics such as experimental design best practices, research involving animal subjects, authorship, and research misconduct. Student learning will be assessed through in-class formative assessments as well as small group presentations during the discussion sessions. The course is recommended for all graduate students and postdocs who are engaged in research and is offered annually in C-term.
Units: 0

ID 527: Fundamentals of Scientific Teaching and Pedagogy

The purpose of this zero credit course is to bolster teaching proficiency for pre-doctoral and postdoctoral trainees through in depth and interactive sessions on the science behind student learning, scientific teaching, assessments and rubrics, active learning, project based learning, inclusive learning environments, teaching philosophies, technology in the classroom, and course design. Participants will learn through both lecture and practicum sessions each week, and will work in small groups to develop a short teachable unit incorporating the techniques learned throughout the course, which they will ultimately present at the conclusion of the series. Students will also develop a statement of teaching philosophy during the course and receive feedback on the statement. The course is recommended for all graduate students and postdocs who are pursuing careers that will entail teaching in higher education as well as those interested in learning the fundamentals of pedagogy and effective teaching strategies. The course is offered annually each Fall.

Units: 0

IDG 598: Systems Engineering Leadership Project

This project-based course is an interdisciplinary exercise that integrates the technical aspects of systems engineering with the challenges of meeting business goals within the framework of the organizational structure. It allows students to apply the skills and knowledge acquired throughout the Systems Engineering Leadership curriculum. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. Each project is normally conducted in teams of two to four students. They are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced systems engineers.

Units: 0

Prerequisites:

Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the engineering leadership project.

IDG 599: Capstone Project Experience in Power Systems Management

This project-based course is an interdisciplinary exercise that integrates the technical aspects of power systems engineering with challenges of meeting business goals within the framework of the corporate organizational structure. It allows the students to apply the skills and knowledge acquired throughout the Power Systems Management curriculum. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. Each project is normally conducted in teams of two to four students. They are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Power Systems profession.

Units: 0

Prerequisites:

Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the capstone project

Manufacturing Engineering

ME/MFE/MTE 5420: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

Units: 2

ME 5370/MTE 5841/MFE 5841: Surface Metrology

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science. Students cannot receive credit for this course if they have received credit for ME 5371/MTE 5843/MFE 5843 Fundamentals of Surface Metrology or the Special Topics (ME 593/MTE 594/MFE 594) version of Fundamentals of Surface Metrology.

Units: 3

ME 5371/MFE 5843/MTE 5843: Fundamentals of Surface Metrology

Surface Metrology is about measuring, characterizing, and analyzing surface topographies or textures. This course covers conventional and developing measurement and characterization of roughness. It emphasizes research and covers a wide variety of applications, including, adhesion, friction, fatigue life, mass transfer, scattering, wear, manufacturing, food science, wetting, physical anthropology, and archeology. Surface metrology has applications in practically all engineering disciplines and sciences. Research principles are applied to critical evaluations of research methods. Students learn multiscale methods for discovering correlations between processing, textures, and behavior , and for discriminating surface textures supposed to be different because of their performance or manufacture. Results support product and process design, and quality assurance. Students create detailed project proposals on topics of their choosing, including literature reviews, preparation and testing of surfaces, measurements, characterizations, and analyses. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594/MFE 594) version of this course, or for ME 5370/MTE 5841/MFE 5841 Surface Metrology.

Units: 2

ME 5385/MFE 5385/MTE 5385: Metal Additive Manufacturing

Additive Manufacturing (AM), popularly known as 3D printing, is a technique in which parts are fabricated in a layer-by-layer fashion. The focus of this course is on direct metal AM processes that are used in aerospace, automobile, medical, and energy industries. The objective of the course is to enable students to understand the working principles of various additive manufacturing processes, assess the suitability of metal AM processes for different designs and applications, apply process design concepts to metal AM processes via analytical and finite element modeling approaches, and have an introductory-level understanding of design for AM. Through the course project, students will have the opportunity to experience hands-on design, manufacturing, and characterization of additively manufactured materials, and will work in an interdisciplinary team of mechanical, materials, and manufacturing engineers. The economics of the manufacturing process will also be addressed, with an emphasis on determining the major cost drivers and discussing cost minimization strategies. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.
Units: 2

MFE/MTE 521: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543
Units: 2

MFE 500: Current Topics in Manufacturing Seminar

This seminar identifies the typical problems involved in a variety of manufacturing operations, and generic approaches for applying advanced technologies to implement operations. Topical areas of application and development such as intelligent materials processing, automated assembly, MRP and JIT scheduling, vision recognition systems, high-speed computer networks, distributed computer control of manufacturing processes and flexible manufacturing systems may be covered. This seminar is coordinated with the undergraduate program in manufacturing engineering. Required for all full-time students.
Units: 0

MFE 510: Control and Monitoring of Manufacturing Processes

Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing and distributed control. Typical applications are considered with lab work.
Units: 3

MFE 511: Application of Industrial Robotics

(Concurrent with ME 4815) This course introduces the student to the field of industrial automation. Topics covered include robot specification and selection, control and drive methods, part presentation, economic justification, safety, implementation, product design and programming languages. The course combines the use of lecture, project work and laboratories that utilize industrial robots. Theory and application of robotic systems will be emphasized.
Units: 2

MFE 520/MTE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.
Units: 3

MFE 531/ME 5431: Computer Integrated Manufacturing

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. Emphasis is placed on CAD/CAM integration. Topics include, part design specification and manufacturing quality, tooling and fixture design, and manufacturing information systems. This course includes a group term project. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE 593D/MFE 594D
Units: 2
Prerequisites:
Background in manufacturing and CAD/CAM, e.g., ME 1800, ES 1310, ME 3820.)

MFE 541/ME 5441: Design for Manufacturability

The problems of cost determination and evaluation of processing alternatives in the designmanufacturing interface are discussed. Approaches for introducing manufacturing capability knowledge into the product design process are covered. An emphasis is placed on part and process simplification, and analysis of alternative manufacturing methods based on such parameters as: anticipated volume, product life cycle, lead time, customer requirements, and quality yield. Lean manufacturing and Six-Sigma concepts and their influence on design quality are included as well. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE594M).
Units: 2

MFE 590: Capstone Project in Manufacturing Engineering

The new capstone course (MFE 590) will provide a practical experience for the students in the M.S. MFE Program to synthesize their learning and to apply knowledge to solving real-world manufacturing problems. The projects will be sponsored by either internal units on campus or external organizations. In addition to a written report, the project results will be formally presented to the class, outside sponsors and other interested parties.
Units: 3

MFE 594: Special Topics

Theoretical and experimental studies in subjects of interest to graduate students in manufacturing engineering.

Units: 3

Prerequisites:

Consent of instructor.) The description of each Special Topics course is attached to the course number as seen on the course schedule posted on the Registrar's website.

MFE 598: Directed Research

Units: 3

MFE 599: Thesis Research

Units: 3

MTE/MFE 521: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

Units: 2

MTE 520/MFE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

Units: 3

Materials Science and Engineering

BME 530/ME 5359/MTE 559: Biomedical Materials

This course is intended to serve as a general introduction to various aspects pertaining to the application of synthetic and natural materials in medicine and healthcare. This course will provide the student with a general understanding of the properties of a wide range of materials used in clinical practice. The physical and mechanical property requirements for the long term efficacy of biomaterials in the augmentation, repair, replacement or regeneration of tissues will be described. The physico-chemical interactions between the biomaterial and the physiological environment will be highlighted. The course will provide a general understanding of the application of a combination of synthetic and biological moieties to elicit a specific physiological response. Examples of the use of biomaterials in drug delivery, theranostic, orthopedic, dental, cardiovascular, ocular, wound closure and the more recent lab-on-chip applications will be outlined. This course will highlight the basic terminology used in this field and provide the background to enable the student to review the latest research in scientific journals. This course will demonstrate the interdisciplinary issues involved in biomaterials design, synthesis, evaluation and analysis, so that students may seek a job in the medical device industry or pursue research in this rapidly expanding field. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/ MTE 594) version of the same course, or for ME/BME 4814 Biomedical Materials.

Units: 2

ME/MFE/MTE 5420: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

Units: 2

ME 5370/MTE 5841/MFE 5841: Surface Metrology

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science. Students cannot receive credit for this course if they have received credit for ME 5371/MTE 5843/MFE 5843 Fundamentals of Surface Metrology or the Special

Topics (ME 593/MTE 594/MFE 594) version of Fundamentals of Surface Metrology.
Units: 3

ME 5371/MFE 5843/MTE 5843: Fundamentals of Surface Metrology
Surface Metrology is about measuring, characterizing, and analyzing surface topographies or textures. This course covers conventional and developing measurement and characterization of roughness. It emphasizes research and covers a wide variety of applications, including, adhesion, friction, fatigue life, mass transfer, scattering, wear, manufacturing, food science, wetting, physical anthropology, and archeology. Surface metrology has applications in practically all engineering disciplines and sciences. Research principles are applied to critical evaluations of research methods. Students learn multiscale methods for discovering correlations between processing, textures, and behavior , and for discriminating surface textures supposed to be different because of their performance or manufacture. Results support product and process design, and quality assurance. Students create detailed project proposals on topics of their choosing, including literature reviews, preparation and testing of surfaces, measurements, characterizations, and analyses. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594/MFE 594) version of this course, or for ME 5370/ MTE 5841/MFE 5841 Surface Metrology.
Units: 2

ME 5385/MFE 5385/MTE 5385: Metal Additive Manufacturing
Additive Manufacturing (AM), popularly known as 3D printing, is a technique in which parts are fabricated in a layer-by-layer fashion. The focus of this course is on direct metal AM processes that are used in aerospace, automobile, medical, and energy industries. The objective of the course is to enable students to understand the working principles of various additive manufacturing processes, assess the suitability of metal AM processes for different designs and applications, apply process design concepts to metal AM processes via analytical and finite element modeling approaches, and have an introductory-level understanding of design for AM. Through the course project, students will have the opportunity to experience hands-on design, manufacturing, and characterization of additively manufactured materials, and will work in an interdisciplinary team of mechanical, materials, and manufacturing engineers. The economics of the manufacturing process will also be addressed, with an emphasis on determining the major cost drivers and discussing cost minimization strategies. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.
Units: 2

ME 5390/MTE 5390: Solar Cells
The objective of this course is to provide students with an understanding of the working principles, design, fabrication and characterization of established and emerging solar cell technologies. Students will be exposed to the electronic properties of semiconductor materials, which are the building blocks of solar cells, and the analysis of photo-generation and extraction of charges in these materials. The course will emphasize the influence of the atomic-, nano- and micro-scale structure of the materials on the solar cell performance. In addition, the challenges of economics and scalability that must be addressed to increase the deployment of solar cells will be discussed. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.
Units: 2

MFE/MTE 521: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543

Units: 2

MFE 520/MTE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

Units: 3

MTE/ME 5847: Materials for Electrochemical Energy Systems

An introductory course on electrochemical engineering, fuel cells and batteries. With escalating oil prices and increasing environmental concerns, increasing attention is being paid to the development of electrochemical devices to replace traditional energy. Here several types of batteries and fuel cells will be discussed. Topics covered include: basic electrochemistry, lithium ion battery, proton exchange membrane fuel cell, solid oxide fuel cell, electrochemical method. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

Units: 2

Recommended Background: ES2001 or equivalent.

MTE/MFE 521: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

Units: 2

MTE 509: Electron Microscopy

This course introduces students to the theory, fundamental operating principles, and specimen preparation techniques of scanning electron microscopy (SEM), transmission electron microscopy (TEM), and energy dispersive x-ray spectroscopy (EDS). The primary emphasis is placed on practical SEM, TEM, and x-ray microanalysis of materials. Topics to be covered include basic principles of the electron microscopy; SEM instrumentation, image formation and interpretation, qualitative and quantitative x-ray microanalysis in SEM; electron diffraction and diffraction contrast imaging in TEM. Various application examples of SEM and TEM in materials research will be discussed. Lab work will be included. The course is available to graduate students.

Units: 2

Recommended Background:

CH 1020, PH 1120, and ES 2001 or equivalent. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

MTE 511/ME 5311: Structure and Properties of Engineering Materials

This course, (along with its companion course MTE 512 Properties and Performance of Engineering Materials), is designed to provide a comprehensive review of the fundamental principles of Materials Science and Engineering for incoming graduate students. In the first part of this 2 course sequence, the structure in materials ranging from the sub-atomic to the macroscopic including nano, micro and macromolecular structures will be discussed to highlight bonding mechanisms, crystallinity and defect patterns. Representative thermodynamic and kinetic aspects such as diffusion, phase diagrams, nucleation and growth and TTT diagrams will be discussed. Major structural parameters that effect of performance in materials including plastics, metallic alloys, ceramics and glasses will be emphasized. The principal processing techniques to shape materials and the effects of processing on structure will be highlighted. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594S

Units: 2

Prerequisites:

senior or graduate standing or consent of the instructor.

MTE 512/ME 531: Properties and Performance of Engineering Materials

The two introductory classes on materials science (MTE 511 and MTE 512) describe the structure-property relationships in materials. The purpose of this class is to provide a basic knowledge of the principles pertaining to the physical, mechanical and chemical properties of materials. The primary focus of this class will be on mechanical properties. The thermal, tensile, compressive, flexural and shear properties of metallic alloys, ceramics and glasses and plastics will be discussed. Fundamental aspects of fracture mechanics and viscoelasticity will be presented. An overview of dynamic properties such as fatigue, impact and creep will be provided. The relationship between the structural parameters and the preceding mechanical properties will be described. Basic composite theories will be presented to describe fiber-reinforced composites and nanocomposites. Various factors associated with material degradation during use will be discussed. Some introductory definitions of electrical and optical properties will be outlined. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594P).

Units: 2

Prerequisites:

MTE 511 and senior or graduate standing or consent of the instructor

MTE 520/MFE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

Units: 3

MTE 526: Advanced Thermodynamics

Thermodynamics of solutions—phase equilibria—Ellingham diagrams, binary and ternary phase diagrams, reactions between gasses and condensed phases, reactions within condensed phases, thermodynamics of surfaces, defects and electrochemistry. Applications to materials processing and degradation will be presented and discussed. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594T).

Units: 2

Prerequisites:

ES 3001, ES 2001

MTE 530: Computational Thermodynamics

The objective of this course is to introduce the basic principles of computational thermodynamics (CALPHAD). Students will be exposed to the basic thermodynamic simulation in single-component, binary, ternary, and higher-order systems for various alloys and ceramics systems. The course will emphasize the linkage of computational thermodynamics with the real industry challenges faced in the next-generation materials design. In addition, the fundamental concepts of multiscale modeling, including the atomic scale, mesoscale and macroscale modeling, will also be introduced to students. Recommended Background: A graduate major in engineering or science is recommended, but not required. It is preferred that students have taken MTE526/ME5326 Advanced Thermodynamics or equivalent courses.

Units: 2

MTE 532: X-Ray Diffraction and Crystallography

This course discusses the fundamentals of crystallography and X-ray diffraction (XRD) of metals, ceramics and polymers. It introduces graduate students to the main issues and techniques of diffraction analysis as they relate to materials. The techniques for the experimental phase identification and determination of phase fraction via XRD will be reviewed. Topics covered include: basic X-ray physics, basic crystallography, fundamentals of XRD, XRD instrumentation and analysis techniques. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594C).

Units: 2

Prerequisites:

ES 2001 or equivalent, and senior or graduate standing in engineering or science.

MTE 540: Analytical Methods in Materials Engineering

Heat transfer and diffusion kinetics are applied to the solution of materials engineering problems. Mathematical and numerical methods for the solutions to Fourier's and Pick's laws for a variety of boundary conditions will be presented and discussed. The primary emphasis is given heat treatment and surface modification processes. Topics to be covered include solutionizing, quenching, and carburization heat treatment.

Units: 3

Prerequisites:

ME 4840 or MTE 511 and MTE 512 or equivalent

MTE 550: Phase Transformations in Materials

This course is intended to provide a fundamental understanding of thermodynamic and kinetic principles associated with phase transformations. The mechanisms of phase transformations will be discussed in terms of driving forces to establish a theoretical background for various physical phenomena. The principles of nucleation and growth and spinodal transformations will be described. The theoretical analysis of diffusion controlled and interface controlled growth will be presented The basic concepts of martensitic transformations will be highlighted. Specific examples will include solidification, crystallization, precipitation, sintering, phase separation and transformation toughening.

Units: 3

Prerequisites:

MTE 511 and MTE 512, ME 4850 or equivalent

MTE 556/ME 5356: Smart Materials

A material whose properties can respond to an external stimulus in a controlled fashion is referred to as a smart or intelligent material. These materials can be made to undergo changes modulus, shape, porosity, electrical conductivity, physical form, opacity, and magnetic properties based on an external stimulus. The stimuli can include temperature, pH, specific molecules, light, magnetic field, voltage and stress. These stimuli-sensitive materials can be utilized as sensors and as vehicles for the controlled delivery of drugs and other biomolecules in medical applications. Smart materials are also becoming important in other biological areas such as bio-separation, biosensor design, tissue engineering, protein folding, and microfluidics. The use of stimuli-sensitive materials is receiving increasing attention in the development of damage tolerant smart structures in aerospace, marine, automotive and earth quake resistant buildings. The use of smart materials is being explored for a range of applications including protective coatings, corrosion barriers, intelligent batteries, fabrics and food packaging. The purpose of this course is to provide an introduction to the various types of smart materials including polymers, ceramic, metallic alloys and composites. Fundamental principles associated with the onset of "smart" property will be highlighted. The principles of self-healable materials based on smart materials will be discussed. The application of smart materials in various fields including sensors, actuators, diagnostics, therapeutics, packaging and other advanced applications will be presented. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594).

Units: 2

MTE 558: Plastics

This course will provide an integrated overview of the design, selection and use of synthetic plastics. The basic chemistry associated with polymerization and the structure of commercial plastics will be described. Various aspects of polymer crystallization and glass transition will be outlined. Salient aspects of fluid flow and heat transfer during the processing of plastics will be highlighted. Fundamentals of the diverse processing operations used to shape plastics and the resulting structures that develop after processing will be discussed. The mechanical behavior of plastics including elastic deformation, rubber elasticity, yielding, viscoelasticity, fracture and creep will be discussed. Plastic degradation and environmental issues associated with recycling and disposal of plastics will be examined. Typical techniques used in the analysis and testing of plastics will be described and a working knowledge of various terminologies used in commercial practice will be provided. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594A).
Units: 2

MTE 561/ME 5361: Mechanical Behavior and Fracture of Materials

The failure and wear-out mechanisms for a variety of materials (metals, ceramics, polymers, composites and microelectronics) and applications will be presented and discussed. Multi-axial failure theories and fracture mechanics will be discussed. The methodology and techniques for reliability analysis will also be presented and discussed. A materials systems approach will be used. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 593C/MTE 594C).
Units: 2
Prerequisites:
ES 2502 and ME 3023 or equivalent, and senior or graduate standing in engineering or science.

MTE 575/ME 4875: Introduction to Nanomaterials and Nanotechnology

This course introduces students to current developments in nanoscale science and technology. The current advance of materials and devices constituting of building blocks of metals, semiconductors, ceramics or polymers that are nanometer size (1-100 nm) are reviewed. The profound implications for technology and science of this research field are discussed. The differences of the properties of matter on the nanometer scale from those on the macroscopic scale due to the size confinement, predominance of interfacial phenomena and quantum mechanics are studied. The main issues and techniques relevant to science and technologies on the nanometer scale are considered. New developments in this field and future perspectives are presented. Topics covered include: fabrication of nanoscale structures, characterization at nanoscale, molecular electronics, nanoscale mechanics, new architecture, nano optics and societal impacts.
Units: 2
Recommended Background:
ES 2001 Introduction to Materials or equivalent

MTE 580: Materials Science and Engineering Seminar

Reports on the state-of-the-art in various areas of research and development in materials science and engineering will be presented by the faculty and outside experts. Reports on graduate student research in progress will also be required.
Units: 3

MTE 594: Special Topics

Theoretical or experimental studies in subjects of interest to graduate students in materials science and engineering.
Units: 0

MTE 5390/ME 5390: Solar Cells

The objective of this course is to provide students with an understanding of the working principles, design, fabrication and characterization of established and emerging solar cell technologies. Students will be exposed to the electronic properties of semiconductor materials, which are the building blocks of solar cells, and the analysis of photo-generation and extraction of charges in these materials. The course will emphasize the influence of the atomic-, nano- and micro-scale structure of the materials on the solar cell performance. In addition, the challenges of economics and scalability that must be addressed to increase the deployment of solar cells will be discussed. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.

Units: 2

MTE 5816: Ceramics and Glasses for Engineering Applications

This course develops an understanding of the processing, structure, property, performance relationships in crystalline and vitreous ceramics. The topics covered include crystal structure, glassy structure, phase diagrams, microstructures, mechanical properties, optical properties, thermal properties, and materials selection for ceramic materials. In addition the methods for processing ceramics for a variety of products will be included. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

Units: 2

Recommended Background:

ES2001 or equivalent.

MTE 5844: Corrosion and Corrosion Control

An introductory course on corrosion; aqueous corrosion, stress corrosion cracking and hydrogen effects in metals will be presented. High-temperature oxidation, carburization and sulfidation will be discussed. Discussions focus on current corrosive engineering problems and research. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

Units: 2

Prerequisites:

MTE 511 and MTE 512 or consent of the instructor.

Mathematical Sciences

BCB 504/MA 584: Statistical Methods in Genetics and Bioinformatics

This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees. Students may not receive credit for both BCB 4004 and BCB 504.

Units: 3

Prerequisites:

knowledge of probability and statistics at the undergraduate level

DS/MA 517: Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data.

Units: 3

Prerequisites:

Some knowledge of integral and differential calculus is recommended.

MA/DS 517: Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data.

Units: 3

Prerequisites:

Some knowledge of integral and differential calculus is recommended.

MA 500: Basic Real Analysis

This course covers basic set theory, topology of Rn, continuous functions, uniform convergence, compactness, infinite series, theory of differentiation and integration. Other topics covered may include the inverse and implicit function theorems and Riemann-Stieltjes integration. Students may not count both MA 3831 and MA 300 toward their undergraduate degree requirements.

Units: 3

MA 501: Engineering Mathematics

This course develops mathematical techniques used in the engineering disciplines. Preliminary concepts will be reviewed as necessary, including vector spaces, matrices and eigenvalues. The principal topics covered will include vector calculus, Fourier transforms, fast Fourier transforms and Laplace transformations. Applications of these techniques for the solution of boundary value and initial value problems will be given. The problems treated and solved in this course are typical of those seen in applications and include problems of heat conduction, mechanical vibrations and wave propagation.

Units: 3

Prerequisites:

A knowledge of ordinary differential equations, linear algebra and multivariable calculus is assumed

MA 502: Linear Algebra

This course provides an introduction to the theory and methods of applicable linear algebra. The goal is to bring out the fundamental concepts and techniques that underlie and unify the many ways in which linear algebra is used in applications. The course is suitable for students in mathematics and other disciplines who wish to obtain deeper insights into this very important subject than are normally offered in undergraduate courses. It is also intended to provide a foundation for further study in subjects such as numerical linear algebra and functional analysis.

Units: 3

MA 503: Lebesgue Measure and Integration

This course begins with a review of topics normally covered in undergraduate analysis courses: open, closed and compact sets; liminf and limsup; continuity and uniform convergence. Next the course covers Lebesgue measure in Rn including the Cantor set, the concept of a sigma-algebra, the construction of a nonmeasurable set, measurable functions, semicontinuity, Egorovs and Lusin's theorems, and convergence in measure. Next we cover Lebesgue integration, integral convergence theorems (monotone and dominated), Tchebyshev's inequality and Tonelli's and Fubini's theorems. Finally Lp spaces are introduced with emphasis on L2 as a Hilbert space. Other related topics will be covered at the instructor's discretion.

Units: 3

Prerequisites:

Basic knowledge of undergraduate analysis is assumed

MA 504: Functional Analysis

This course will give a comprehensive presentation of fundamental concepts and theorems in Banach and Hilbert spaces. Whenever possible, the theory will be illustrated by examples in Lebesgue spaces. Topics include: The Hahn-Banach theorems, the Uniform Boundedness principle (Banach-Steinhaus Theorem), the Open Mapping and Closed Graph theorems, and weak topologies and convergence. Additional topics will be covered at the instructor's discretion.

Units: 3

Prerequisites:

MA 503 or equivalent

MA 505: Complex Analysis

This course will provide a rigorous and thorough-treatment of the theory of functions of one complex variable. The topics to be covered include complex numbers, complex differentiation, the Cauchy-Riemann equations, analytic functions, Cauchy's theorem, complex integration, the Cauchy integral formula, Liouville's theorem, the Gauss mean value theorem, the maximum modulus theorem, Rouche's theorem, the Poisson integral formula, Taylor-Laurent expansions, singularity theory, conformal mapping with applications, analytic continuation, Schwarz's reflection principle and elliptic functions.

Units: 3

Prerequisites:

knowledge of undergraduate analysis

MA 508: Mathematical Modeling

This course introduces mathematical modelbuilding using dimensional analysis, perturbation theory and variational principles. Models are selected from the natural and social sciences according to the interests of the instructor and students. Examples are: planetary orbits, spring-mass systems, fluid flow, isomers in organic chemistry, biological competition, biochemical kinetics and physiological flow. Computer simulation of these models will also be considered.

Units: 3

Prerequisites:

knowledge of ordinary differential equations and of analysis at the level of MA 501 is assumed

MA 509: Stochastic Modeling

This course gives students a background in the theory and methods of probability, stochastic processes and statistics for applications. The course begins with a brief review of basic probability, discrete and continuous random variables, expectations, conditional probability and basic statistical inference. Topics covered in greater depth include generating functions, limit theorems, basic stochastic processes, discrete and continuous time Markov chains, and basic queuing theory including M/M/1 and M/G/l queues. This course is offered by special arrangement only, based on expressed student interest.

Units: 3

Prerequisites:

knowledge of basic probability at the level of MA 2631 and statistics at the level of MA 2612 is assumed.

MA 510/CS 522: Numerical Methods

This course provides an introduction to a broad range of modern numerical techniques that are widely used in computational mathematics, science, and engineering. It is suitable for both mathematics majors and students from other departments. It covers introductory-level material for subjects treated in greater depth in MA 512 and MA 514 and also topics not addressed in either of those courses. Subject areas include numerical methods for systems of linear and nonlinear equations, interpolation and approximation, differentiation and integration, and differential equations. Specific topics include basic direct and iterative methods for linear systems; classical rootfinding methods; Newton's method and related methods for nonlinear systems; fixed-point iteration; polynomial, piecewise polynomial, and spline interpolation methods; least-squares approximation; orthogonal functions and approximation; basic techniques for numerical differentiation; numerical integration, including adaptive quadrature; and methods for initial-value problems for ordinary differential equations. Additional topics may be included at the instructor's discretion as time permits. Both theory and practice are examined. Error estimates, rates of convergence, and the consequences of finite precision arithmetic are also discussed. Topics from linear algebra and elementary functional analysis will be introduced as needed. These may include norms and inner products, orthogonality and orthogonalization, operators and projections, and the concept of a function space.

Units: 3

Prerequisites:

knowledge of undergraduate linear algebra and differential equations is assumed, as is familiarity with MATLAB or a higher-level programming language

MA 511: Applied Statistics for Engineers and Scientists

This course is an introduction to statistics for graduate students in engineering and the sciences. Topics covered include basic data analysis, issues in the design of studies, an introduction to probability, point and interval estimation and hypothesis testing for means and proportions from one and two samples, simple and multiple regression, analysis of one and two-way tables, one-way analysis of variance. As time permits, additional topics, such as distribution-free methods and the design and analysis of factorial studies will be considered.
Units: 3
Prerequisites:
Integral and differential calculus

MA 512: Numerical Differential Equations

This course begins where MA 510 ends in the study of the theory and practice of the numerical solution of differential equations. Central topics include a review of initial value problems, including Euler's method, Runge-Kutta methods, multi-step methods, implicit methods and predictor-corrector methods; the solution of two-point boundary value problems by shooting methods and by the discretization of the original problem to form systems of nonlinear equations; numerical stability; existence and uniqueness of solutions; and an introduction to the solution of partial differential equations by finite differences. Other topics might include finite element or boundary element methods, Galerkin methods, collocation, or variational methods.
Units: 3
Prerequisites:
graduate or undergraduate numerical analysis. Knowledge of a higher-level programming language is assumed

MA 514: Numerical Linear Algebra

This course provides students with the skills necessary to develop, analyze and implement computational methods in linear algebra. The central topics include vector and matrix algebra, vector and matrix norms, the singular value decomposition, the LU and QR decompositions, Householder transformations and Givens rotations, and iterative methods for solving linear systems including Jacobi, Gauss-Seidel, SOR and conjugate gradient methods; and eigenvalue problems. Applications to such problem areas as least squares and optimization will be discussed. Other topics might include: special linear systems, such as symmetric, positive definite, banded or sparse systems; preconditioning; the Cholesky decomposition; sparse tableau and other least-square methods; or algorithms for parallel architectures.
Units: 3
Prerequisites:
basic knowledge of linear algebra or equivalent background. Knowledge of a higher-level programming language is assumed

MA 520: Fourier Transforms and Distributions

The course will cover L1, L2, L^{∞} and basic facts from Hilbert space theory (Hilbert basis, projection theorems, Riesz theory). The first part of the course will introduce Fourier series: the L2 theory, the C^{∞} theory: rate of convergence, Fourier series of real analytic functions, application to the trapezoidal rule, Fourier transforms in L1, Fourier integrals of Gaussians, the Schwartz class S, Fourier transforms and derivatives, translations, convolution, Fourier transforms in L2, and characteristic functions of probability distribution functions. The second part of the course will cover tempered distributions and applications to partial differential equations. Other related topics will be covered at the instructor's discretion.

Units: 3

Prerequisites:

MA 503

MA 521: Partial Differential Equations

This course considers a variety of material in partial differential equations (PDE). Topics covered will be chosen from the following: classical linear elliptic, parabolic and hyperbolic equations and systems, characteristics, fundamental/Green's solutions, potential theory, the Fredholm alternative, maximum principles, Cauchy problems, Dirichlet/Neumann/Robin problems, weak solutions and variational methods, viscosity solutions, nonlinear equations and systems, wave propagation, free and moving boundary problems, homogenization. Other topics may also be covered.

Units: 3

Prerequisites:

MA 503 or equivalent

MA 522: Hilbert Spaces and Applications to PDE

The course covers Hilbert space theory with special emphasis on applications to linear ODs and PDEs. Topics include spectral theory for linear operators in n-dimensional and infinite dimensional Hilbert spaces, spectral theory for symmetric compact operatos, linear and bilinear forms, Riesz and Lax-Milgram theorems, weak derivatives, Sobolev spaces H1, H2, Rellich compactness theorem, weak and classical solutions for Dirichlet and Neumann problems in one variable and in Rn, Dirichlet variational principle, eigenvalues and eigenvectors. Other related topics will be covered at the instructor's discretion.

Units: 3

Prerequisites:

MA 503

MA 524: Convex Analysis and Optimization

This course covers topics in functional analysis that are critical to the study of convex optimization problems. The first part of the course will include the minimization theory for quadratic and convex functionals on convex sets and cones, the Legendre-Fenchel duality, variational inequalities and complementarity systems. The second part will include optimal stopping time problems in deterministic control, value functions and Hamilton-Jacobi inequalities and linear and quadratic programming, duality and Kuhn-Tucker multipliers. Other related topics will be covered at the instructor's discretion.

Units: 3

Prerequisites:

MA 503

MA 525: Optimal Control and Design with Composite Materials I

Modern technology involves a wide application of materials with internal structure adapted to environmental demands. This, the first course in a two-semester sequence, will establish a theoretical basis for identifying structures that provide optimal response to prescribed external factors. Material covered will include basics of the calculus of variations: Euler equations; transversality conditions; Weierstrass-Erdmann conditions for corner points; Legendre, Jacobi and Weierstrass conditions; Hamiltonian form of the necessary conditions; and Noether's theorem. Pontryagin's maximum principle in its original lumped parameter form will be put forth as well as its distributed parameter extension. Chattering regimes of control and relaxation through composites will be introduced at this point. May be offered by special arrangement.

Units: 3

MA 526: Optimal Control and Design with Composite Materials II

Topics presented will include basics of homogenization theory. Bounds on the effective properties of composites will be established using the translation method and Hashin-Shtrikman variational principles. The course concludes with a number of examples demonstrating the use of the theory in producing optimal structural designs. The methodology given in this course turns the problem of optimal design into a problem of rigorous mathematics. This course can be taken independently or as the sequel to MA 525.

Units: 3

MA 528: Measure Theoretic Probability Theory

This course is designed to give graduate students interested in financial mathematics and stochastic analysis the necessary background in measure-theoretic probability and provide a theoretical foundation for Ph.D. students with research interests in analysis and mathematical statistics. Besides classical topics such as the axiomatic foundations of probability, conditional probabif ities and independence, random variables and their distributions, and limit theorems, this course focuses on concepts crucial for the understanding of stochastic processes and quantitative finance: conditional expectations, filtrations and martingales as well as change of measure techniques and the Radon-Nikodym theorem. A wide range of illustrative examples from a topic chosen by the instructor's discretion (e.g financial mathematics, signal processing, actuarial mathematics) will be presented.
Units: 3
Prerequisites:
MA 500 Basic Real Analysis or equivalent

MA 529: Stochastic Processes

This course is designed to introduce students to continuous-time stochastic processes. Stochastic processes play a central role in a wide range of applications from signal processing to finance and also offer an alternative novel viewpoint to several areas of mathematical analysis, such as partial differential equations and potential theory. The main topics for this course are martingales, maximal inequalities and applications, optimal stopping and martingale convergence theorems, the strong Markov property, stochastic integration, Ito's formula and applications, martingale representation theorems, Girsanov's theorem and applications, and an introduction to stochastic differential equations, the Feynman-Kac formula, and connections to partial differential equations. Optional topics (at the instructor's discretion) include Markov processes and Poisson-and jump-processes.
Units: 3
Prerequisites:
MA 528. Measure-Theoretic Probability Theory, which can be taken concurrently (or, with special permission by the instructor, MA 540)

MA 530: Discrete Mathematics

This course provides the student of mathematics or computer science with an overview of discrete structures and their applications, as well as the basic methods and proof techniques in combinatorics. Topics covered include sets, relations, posets, enumeration, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus.
Units: 3
Prerequisites:
college math at least through calculus. Experience with recursive programming is helpful, but not required

MA 533: Discrete Mathematics II

This course is designed to provide an in-depth study of some topics in combinatorial mathematics and discrete optimization. Topics may vary from year to year. Topics covered include, as time permits, partially ordered sets, lattices, matroids, matching theory, Ramsey theory, discrete programming problems, computational complexity of algorithms, branch and bound methods.
Units: 3

MA 535: Algebra

Fundamentals of group theory: homomorphisms and the isomorphism theorems, finite groups, structure of finitely generated Abelian groups. Structure of rings: homomorphisms, ideals, factor rings and the isomorphism theorems, integral domains, factorization. Field theory: extension fields, finite fields, theory of equations. Selected topics from: Galois theory, Sylow theory, Jordan-Holder theory, Polya theory, group presentations, basic representation theory and group characters, modules. Applications chosen from mathematical physics, Grobner bases, symmetry, cryptography, error-correcting codes, number theory.
Units: 3

MA 540/4631: Probability and Mathematical Statistics I

Intended for advanced undergraduates and beginning graduate students in the mathematical sciences, and for others intending to pursue the mathematical study of probability and statistics. Topics covered include axiomatic foundations, the calculus of probability, conditional probability and independence, Bayes' Theorem, random variables, discrete and continuous distributions, joint, marginal and conditional distributions, covariance and correlation, expectation, generating functions, exponential families, transformations of random variables, types of convergence, laws of large numbers the Central Limit Theorem, Taylor series expansion, the delta method.

Units: 3

Prerequisites:

knowledge of basic probability at the level of MA 2631 and of advanced calculus at the level of MA 3831/3832 is assumed

MA 541/4632: Probability and Mathematical Statistics II

This course is designed to provide background in principles of statistics. Topics covered include estimation criteria: method of moments, maximum likelihood, least squares, Bayes, point and interval estimation, Fisher's information, Cramer-Rao lower bound, sufficiency, unbiasedness, and completeness, Rao-Blackwell Theorem, efficiency, consistency, interval estimation pivotal quantities, Neyman-Person Lemma, uniformly most powerful tests, unbiased, invariant and similar tests, likelihood ratio tests, convex loss functions, risk functions, admissibility and minimaxity, Bayes decision rules.

Units: 3

Prerequisites:

knowledge of the material in MA 340 is assumed

MA 542: Regression Analysis

Regression analysis is a statistical tool that utilizes the relation between a response variable and one or more predictor variables for the purposes of description, prediction and/or control. Successful use of regression analysis requires an appreciation of both the theory and the practical problems that often arise when the technique is employed with real-world data. Topics covered include the theory and application of the general linear regression model, model fitting, estimation and prediction, hypothesis testing, the analysis of variance and related distribution theory, model diagnostics and remedial measures, model building and validation, and generalizations such as logistic response models and Poisson regression. Additional topics may be covered as time permits. Application of theory to real-world problems will be emphasized using statistical computer packages.

Units: 3

Prerequisites:

knowledge of probability and statistics at the level of MA 311 and of matrix algebra is assumed

MA 543/DS 502: Statistical Methods for Data Science

Statistical Methods for Data Science surveys the statistical methods most useful in data science applications. Topics covered include predictive modeling methods, including multiple linear regression, and time series, data dimension reduction, discrimination and classification methods, clustering methods, and committee methods. Students will implement these methods using statistical software.

Units: 3

Prerequisites:

Statistics at the level of MA 2611 and MA 2612 and linear algebra at the level of MA 2071.

MA 546: Design and Analysis of Experiments

Controlled experiments—studies in which treatments are assigned to observational units— are the gold standard of scientific investigation. The goal of the statistical design and analysis of experiments is to (1) identify the factors which most affect a given process or phenomenon; (2) identify the ways in which these factors affect the process or phenomenon, both individually and in combination; (3) accomplish goals 1 and 2 with minimum cost and maximum efficiency while maintaining the validity of the results. Topics covered in this course include the design, implementation and analysis of completely randomized complete block, nested, split plot, Latin square and repeated measures designs. Emphasis will be on the application of the theory to real data using statistical computer packages.

Units: 3

Prerequisites:

knowledge of basic probability and statistics at the level of MA 511 is assumed

MA 547: Design and Analysis of Observational and Sampling Studies

Like controlled experiments, observational studies seek to establish cause-effect relationships, but unlike controlled experiments, they lack the ability to assign treatments to observational units. Sampling studies, such as sample surveys, seek to characterize aspects of populations by obtaining and analyzing samples from those populations. Topics from observational studies include: prospective and retrospective studies; overt and hidden bias; adjustments by stratification and matching. Topics from sampling studies include: simple random sampling and associated estimates for means, totals, and proportions; estimates for subpopulations; unequal probability sampling; ratio and regression estimation; stratified, cluster, systematic, multistage, double sampling designs, and, time permitting, topics such as model-based sampling, spatial and adaptive sampling.

Units: 3

Prerequisites:

knowledge of basic probability and statistics, at the level of MA 511 is assumed

MA 548: Quality Control

This course provides the student with the basic statistical tools needed to evaluate the quality of products and processes. Topics covered include the philosophy and implementation of continuous quality improvement methods, Shewhart control charts for variables and attributes, EWMA and Cusum control charts, process capability analysis, factorial and fractional factorial experiments for process design and improvement, and response surface methods for process optimization. Additional topics will be covered as time permits. Special emphasis will be placed on realistic applications of the theory using statistical computer packages.

Units: 3

Prerequisites:

knowledge of basic probability and statistic, at the level of MA 511 is assumed

MA 549: Analysis of Lifetime Data

Lifetime data occurs frequently in engineering, where it is known as reliability or failure time data, and in the biomedical sciences, where it is known as survival data. This course covers the basic methods for analyzing such data. Topics include: probability models for lifetime data, censoring, graphical methods of model selection and analysis, parametric and distribution-free inference, parametric and distribution-free regression methods. As time permits, additional topics such as frailty models and accelerated life models will be considered. Special emphasis will be placed on realistic applications of the theory using statistical computer packages.

Units: 3

Prerequisites:

knowledge of basic probability and statistics at the level of MA 511 is assumed

MA 550: Time Series Analysis

Time series are collections of observations made sequentially in time. Examples of this type of data abound in many fields ranging from finance to engineering. Special techniques are called for in order to analyze and model these data. This course introduces the student to time and frequency domain techniques, including topics such as autocorrelation, spectral analysis, and ARMA and ARIMA models, Box-Jenkins methodology, fitting, forecasting, and seasonal adjustments. Time permitting, additional topics will be chosen from: Kalman filter, smoothing techniques, Holt-Winters procedures, FARIMA and GARCH models, and joint time-frequency methods such as wavelets. The emphasis will be in application to real data situations using statistical computer packages.

Units: 3

Prerequisites:

knowledge of MA 511 is assumed. Knowledge of MA 541 is also assumed, but may be taken concurrently

MA 551: Computational Statistics

Computational statistics is an essential component of modern statistics that often requires efficient algorithms and programing strategies for statistical learning and data analysis. This course will introduce principles and techniques of statistical computing and data management necessary for computationally intensive statistical analysis especially for big data. Topics covered include management of large data (data structure, data query), parallelized data analyses, stochastic simulations (Monte Carlo methods, permutation-based inference), numerical optimization in statistical inference (deterministic and stochastic convex analysis, EM algorithm, etc.), randomization methods (bootstrap methods), etc. Students will use these techniques while engaging in hands-on projects with real data. Students who have taken the MA590 version of this course cannot also earn credit for MA 551.

Prerequisites:

No previous programming knowledge/experience is assumed. Some knowledge of probability and statistics, or MA511 equivalent is recommended.

MA 552: Distribution-Free and Robust Statistical Methods

Distribution-free statistical methods relax the usual distributional modeling assumptions of classical statistical methods. Robust methods are statistical procedures that are relatively insensitive to departures from typical assumptions, while retaining the expected behavior when assumptions are satisfied. Topics covered include, time permitting, order statistics and ranks; classical distribution-free tests such as the sign, Wilcoxon signed rank, and Wilcoxon rank sum tests, and associated point estimators and confidence intervals; tests pertaining to one and two-way layouts; the Kolmogorov-Smirnov test; permutation methods; bootstrap and Monte Carlo methods; M, L, and R estimators, regression, kernel density estimation and other smoothing methods. Comparisons will be made to standard parametric methods.

Units: 3

Prerequisites:

knowledge of MA 541 is assumed, but may be taken concurrently

MA 554: Applied Multivariate Analysis

This course is an introduction to statistical methods for analyzing multivariate data. Topics covered are multivariate sampling distributions, tests and estimation of multivariate normal parameters, multivariate ANOVA, regression, discriminant analysis, cluster analysis, factor analysis and principal components. Additional topics will be covered as time permits. Students will be required to analyze real data using one of the standard packages available.

Units: 3

Prerequisites:

knowledge of MA 541 is assumed, but may be taken concurrently. Knowledge of matrix algebra is assumed

MA 556: Applied Bayesian Statistics

Bayesian statistics makes use of an inferential process that models data summarizing the results in terms of probability distributions for the model parameters. A key feature is that in the Bayesian approach, past information can be updated with new data in an elegant way in order to aid in decision making. Topics included in the courses: statistical decision theory, the Bayesian inferential framework (model specification, model fitting and model checking); computational methods for posterior simulation integration; regression models, hierarchical models, and ANOVA; time permitting, additional topics will include generalized linear models, multivariate models, missing data problems, and time series analysis.

Units: 3

Prerequisites:

knowledge of MA 541 is assumed

MA 557: Graduate Seminar in Applied Mathematics

This seminar introduces students to modern issues in Applied Mathematics. In the seminar, students and faculty will read and discuss survey and research papers, make and attend presentations, and participate in brainstorming sessions toward the solution of advanced mathematical problems.

Units: 0

MA 559: Statistics Graduate Seminar

This seminar introduces students to issues and trends in modern statistics. In the seminar, students and faculty will read and discuss survey and research papers, make and attend presentations, and participate in brainstorming sessions toward the solution of advanced statistical problems.

Units: 1

MA 560: Graduate Seminar

Designed to introduce graduate students to study of original papers and afford them opportunity to give account of their work by talks in the seminar.

Units: 0

MA 562 A and B.: Professional Master's Seminar

This seminar will introduce professional masters students to topics related to general writing, presentation, group communication and interviewing skills, and will provide the foundations to successful cooperation within interdisciplinary team environments. All full-time students will be required to take both components A and B of the seminar during their professional masters studies.

Units: 0

MA 571: Financial Mathematics I

This course provides an introduction to many of the central concepts in mathematical finance. The focus of the course is on arbitrage-based pricing of derivative securities. Topics include stochastic calculus, securities markets, arbitrage-based pricing of options and their uses for hedging and risk management, forward and futures contracts, European options, American options, exotic options, binomial stock price models, the Black-Scholes-Merton partial differential equation, risk-neutral option pricing, the fundamental theorems of asset pricing, sensitivity measures ("Greeks"), and Merton's credit risk model.

Units: 3

Prerequisites:

MA 540, which can be taken concurrently

MA 572: Financial Mathematics II

The course is devoted to the mathematics of fixed income securities and to the financial instruments and methods used to manage interest rate risk. The first topics covered are the term-structure of interest rates, bonds, futures, interest rate swaps and their uses as investment or hedging tools and in asset-liability management. The second part of the course is devoted to dynamic term-structure models, including risk-neutral interest rate trees, the Heath-Jarrow-Morton model, Libor market models, and forward measures. Applications of these models are also covered, including the pricing of non-linear interest rate derivatives such as caps, floors, collars, swaptions and the dynamic hedging of interest rate risk. The course concludes with the coverage of mortgage-backed and asset-backed securities.

Units: 3

Prerequisites:

MA 571

MA 573: Computational Methods of Financial Mathematics

Most realistic quantitative finance models are too complex to allow explicit analytic solutions and are solved by numerical computational methods. The first part of the course covers the application of finite difference methods to the partial differential equations and interest rate models arising in finance. Topics included are explicit, implicit and Crank-Nicholson finite difference schemes for fixed and free boundary value problems, their convergence and stability. The second part of the course covers Monte Carlo simulation methods, including random number generation, variance reduction techniques and the use of low discrepancy sequences.

Units: 3

Prerequisites:

MA 571 and programming skills at the level of MA 579, which can be taken concurrently

MA 574: Portfolio Valuation and Risk Management

Balancing financial risks vs returns by the use of asset diversification is one of the fundamental tasks of quantitative financial management. This course is devoted to the use of mathematical optimization and statistics to allocate assets, to construct and manage portfolios and to measure and manage the resulting risks. The fist part of the course covers Markowitz's mean-variance optimization and efficient frontiers, Sharpe's single index and capital asset pricing models, arbitrage pricing theory, structural and statistical multifactor models, risk allocation and risk budgeting. The second part of the course is devoted to the intertwining of optimization and statistical methodologies in modern portfolio management, including resampled efficiency, robust and Bayesian statistical methods, the Black-Litterman model and robust portfolio optimization.

Units: 3

MA 575: Market and Credit Risk Models and Management

The objective of the course is to familiarize students with the most important quantitative models and methods used to measure and manage financial risk, with special emphasis on market and credit risk. The course starts with the introduction of metrics of risk such as volatility, value-at-risk and expected shortfall and with the fundamental quantitative techniques used in financial risk evaluation and management. The next section is devoted to market risk including volatility modeling, time series, non-normal heavy tailed phenomena and multivariate notions of codependence such as copulas, correlations and tail-dependence. The final section concentrates on credit risk including structural and dynamic models and default contagion and applies the mathematical tools to the valuation of default contingent claims including credit default swaps, structured credit portfolios and collateralized debt obligations.
Units: 3
Prerequisites:
knowledge of MA 540 assumed but can be taken concurrently

MA 579: Financial Programming Workshop

The objective is to elevate the students' computer programming skills to the semi-professional level required in quantitative finance. Participants learn through hands-on experience by working on a structured set of mini projects from computational finance under the guidance of an experienced trainer and the faculty in charge. The programming language used may be C++, MATLAB, R/S, VB or another language widely used in quantitative finance and may alternate from year to year.
Units: 1
Prerequisites:
Intermediate scientific programming skills

MA 584/BCB 504: Statistical Methods in Genetics and Bioinformatics

This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees. Students may not receive credit for both MA 584 and MA 4603.
Units: 3
Prerequisites:
knowledge of probability and statistics at the undergraduate level

MA 590: Special Topics

Courses on special topics are offered under this number. Contact the Mathematical Sciences Department for current offerings.
Units: 3

MA 595: Independent Study

Supervised independent study of a topic of mutual interest to the instructor and the student.
Units: 1

MA 596: Master's Capstone

The Master's Capstone is designed to integrate classroom learning with real-world practice. It can consist of a project, a practicum, a research review report or a research proposal. A written report and a presentation are required.
Units: 1

MA 598: Professional Master's Project

This project will provide the opportunity to apply and extend the material studied in the coursework to the study of a real-world problem originating in the industry. The project will be a capstone integrating industrial experience with the previously acquired academic knowledge and skills. The topic of the project will come from a problem generated in industry, and could originate from prior internship or industry experience of the student. The student will prepare a written project report and make a presentation before a committee including the faculty advisor, at least one additional WPI faculty member and representatives of a possible industrial sponsor. The advisor of record must be a faculty member of the WPI Mathematical Sciences Department. The student must submit a written project proposal for approval by the Graduate Committee prior to registering for the project.
Units: 1

MA 599: Thesis

Research study at the masters level.
Units: 1

MA 698: Ph.D. Project

Ph.D. project work.
Units: 1

MA 699: Dissertation

Research study at the Ph.D. level.
Units: 1

Mathematics for Educators

MME/SEME 524-25: Probability, Statistics and Data Analysis I, II

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills: • Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena. • Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized. • Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data. • Design of experiments and sampling studies - the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

Units: 4

MME 518: Geometrical Concepts

This course focuses primarily on the foundations and applications of Euclidean and non-Euclidean geometries. The rich and diverse nature of the subject also implies the need to explore other topics, for example, chaos and fractals. The course incorporates collaborative learning and the investigation of ideas through group projects. Possible topics include geometrical software and computer graphics, tiling and tessellations, two- and three-dimensional geometry, inversive geometry, graphical representations of functions, model construction, fundamental relationship between algebra and geometry, applications of geometry, geometry transformations and projective geometry, and convexity.
Units: 3

MME 522: Applications of Calculus

There are three major goals for this course: to establish the underlying principles of calculus, to reinforce students' calculus skills through investigation of applications involving those skills, and to give students the opportunity to develop projects and laboratory assignments for use by first-year calculus students. The course will focus heavily on the use of technology to solve problems involving applications of calculus concepts. In addition, MME students will be expected to master the mathematical rigor of these calculus concepts so that they will be better prepared to develop their own projects and laboratory assignments. For example, if an MME student chose to develop a lab on convergence of sequence, he/she would be expected to understand the rigorous definition of convergence and how to apply it to gain sufficient and/or necessary conditions for convergence. The process of developing these first-year calculus assignments will enable the MME students to increase their own mathematical understanding of concepts while learning to handle mathematical and computer issues which will be encountered by their own calculus students. Their understanding of the concepts and applications of calculus will be further reinforced through computer laboratory assignments and group projects. Applications might include exponential decay of drugs in the body, optimal crankshaft design, population growth, or development of cruise control systems.
Units: 2
Prerequisites:
MME 532

MME 523: Analysis with Applications

This course introduces students to mathematical analysis and its use in modeling. It will emphasize topics of calculus (including multidimensional) in a rigorous way. These topics will be motivated by their usefulness for understanding concepts of the calculus and for facilitating the solutions of engineering and science problems. Projects involving applications and appropriate use of technology will be an essential part of the course. Topics covered may include dynamical systems and differential equations; growth and decay; equilibrium; probabilistic dynamics; optimal decisions and reward; applying, building and validating models; functions on n-vectors; properties of functions; parametric equations; series; applications such as pendulum problems; electromagnetism; vibrations; electronics; transportation; gravitational fields; and heat loss.
Units: 2
Prerequisites:
MME 532

MME 526-27: Linear Models I, II

This two-course sequence imparts computational skills, particularly those involving matrices, to deepen understanding of mathematical structure and methods of proof; it also includes discussion on a variety of applications of the material developed, including linear optimization. Topics in this sequence may include systems of linear equations, vector spaces, linear independence, bases, linear transformations, determinants, eigenvalues and eigenvectors, systems of linear inequalities, linear programming problems, basic solutions, duality and game theory. Applications may include economic models, computer graphics, least squares approximation, systems of differential equations, graphs and networks, and Markov processes.

Units: 4

Prerequisites:

MME 532

MME 528: Mathematical Modeling and Problem Solving

This course introduces students to the process of developing mathematical models as a means for solving real problems. The course will encompass several different modeling situations that utilize a variety of mathematical topics. The mathematical fundamentals of these topics will be discussed, but with continued reference to their use in finding the solutions to problems. Problems to be covered include balance in small group behavior, traffic flow, air pollution flow, group decision making, transportation, assignment, project planning and the critical path method, genetics, inventory control and queueing.

Units: 2

Prerequisites:

MME 532

MME 529: Numbers, Polynomials and Algebraic Structures

This course enables secondary mathematics teachers to see how commonly taught topics such as number systems and polynomials fit into the broader context of algebra. The course will begin with treatment of arithmetic, working through Euclid's algorithm and its applications, the fundamental theorem of arithmetic and its applications, multiplicative functions, the Chinese remainder theorem and the arithmetic of Z/n. This information will be carried over to polynomials in one variable over the rational and real numbers, culminating in the construction of root fields for polynomials via quotients of polynomial rings. Arithmetic in the Gaussian integers and the integers in various other quadratic fields (especially the field of cube roots of unity) will be explored through applications such as the generation of Pythagorean triples and solutions to other Diophantine equations (like finding integersided triangles with a 60 degree angle). The course will then explore cyclotomy, and the arithmetic in rings of cyclotomic integers. This will culminate in Gauss's construction of the regular 5-gon and 17-gon and the impossibility of constructing a 9-gon or trisecting a 60-degree angle. Finally, solutions of cubics and quartics by radicals will be studied. All topics will be based on the analysis of explicit calculations with (generalized) numbers. The proposed curriculum covers topics that are part of the folklore for high school mathematics (the impossibility of certain ruler and compass constructions), but that many teachers know only as facts. There are also many applications of the ideas that will allow the teachers to use results and ideas from abstract algebra to construct for their students problems that have manageable solutions.

Units: 2

MME 531: Discrete Mathematics

This course deals with concepts and methods which emphasize the discrete nature in many problems and structures. The rapid growth of this branch of mathematics has been inspired by its wide range of applicability to diverse fields such as computer science, management, and biology. The essential ingredients of the course are: Combinatorics -The Art of Counting. Topics include basic counting principles and methods such as recurrence relations, generating functions, the inclusion-exclusion principle and the pigeonhole principle. Applications may include block designs, latin squares, finite projective planes, coding theory, optimization and algorithmic analysis. Graph Theory. This includes direct graphs and networks. Among the parameters to be examined are traversibility, connectivity, planarity, duality and colorability.

Units: 3

MME 532: Differential Equations

This course would have concepts and techniques for both Ordinary and Partial Differential Equations. Topics from ordinary differential equations include existence and uniqueness for first order, single variable problems as well as separation of variables and linear methods for first order problems. Second order, linear equations would be solved for both the homogeneous and non homogeneous cases. The phenomena of beats and resonance would be analyzed. The Laplace Transform would be introduced for appropriate second order nonhomogeneous problems. Partial Differential Equations would focus on boundary value problems arising from the Heat and Wave equations in one variable. Fourier Series expansions would be used to satisfy initial conditions and the concepts of orthogonality and convergence addressed.

Units: 2

MME 592/SEME 602: Project Preparation (Part of a 3-Course Sequence with Mme 594 and Mme 596)

Students will research and develop a mathematical topic or pedagogical technique. The project will typically lead to classroom implementation; however, a project involving mathematical research at an appropriate level of rigor will also be acceptable. Preparation will be completed in conjunction with at least one faculty member from the Mathematical Sciences Department and will include exhaustive research on the proposed topic. The course will result in a detailed proposal that will be presented to the MME Project Committee for approval; continuation with the project is contingent upon this approval.

Units: 2

MME 594/SEME 604: Project Implementation

Students will implement and carry out the project developed during the project preparation course. Periodic contact and/or observations will be made by the project advisor (see MME 592 Project Preparation) in order to provide feedback and to ensure completion of the proposed task. Data for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.

Units: 2

MME 596/SEME 606: Project Analysis and Report

Students will complete a detailed statistical analysis of any data collected during the project implementation using techniques from MME 524-525 Probability, Statistics, and Data Analysis. The final report will be a comprehensive review of the relevant literature, project description, project implementation, any statistical results and conclusions. Project reports will be subject to approval by the MME Project committee and all students will be required to present their project to the mathematical sciences faculty. Course completion is contingent upon approval of the report and satisfactory completion of the presentation.

Units: 2

SEME/MME 524-25: Probability, Statistics and Data Analysis I, II

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills: • Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena. • Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized. • Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data. • Design of experiments and sampling studies — the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

Units: 2

Mechanical Engineering

BME/ME 550: Tissue Engineering
This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented.
Units: 3
Prerequisites:
A first course in biomaterials equivalent to BME/ME 4814 and a basic understanding of cell biology and physiology. Admission of undergraduate students requires the permission of the instructor

BME/ME 552: Tissue Mechanics
This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties, and design of medical devices and prostheses.
Units: 3
Prerequisites:
An understanding of basic continuum mechanics

BME 530/ME 5359/MTE 559: Biomedical Materials
This course is intended to serve as a general introduction to various aspects pertaining to the application of synthetic and natural materials in medicine and healthcare. This course will provide the student with a general understanding of the properties of a wide range of materials used in clinical practice. The physical and mechanical property requirements for the long term efficacy of biomaterials in the augmentation, repair, replacement or regeneration of tissues will be described. The physico-chemical interactions between the biomaterial and the physiological environment will be highlighted. The course will provide a general understanding of the application of a combination of synthetic and biological moieties to elicit a specific physiological response. Examples of the use of biomaterials in drug delivery, theranostic, orthopedic, dental, cardiovascular, ocular, wound closure and the more recent lab-on-chip applications will be outlined. This course will highlight the basic terminology used in this field and provide the background to enable the student to review the latest research in scientific journals. This course will demonstrate the interdisciplinary issues involved in biomaterials design, synthesis, evaluation and analysis, so that students may seek a job in the medical device industry or pursue research in this rapidly expanding field. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/ MTE 594) version of the same course, or for ME/BME 4814 Biomedical Materials.
Units: 2

BME 533/ME 5503: Medical Device Innovation and Development
The goal of this course is to introduce medical device innovation strategies, design and development processes, and provide students with an understanding of how medical device innovations are brought from concept to clinical adoption. Students will have opportunities to practice medical device innovation through a team-based course project. Specific learning outcomes include describing and applying medical device design and development concepts such as value proposition, iterative design, concurrent design and manufacturing, intellectual property, and FDA regulation; demonstrating an understanding of emerging themes that are shaping medical device innovation; demonstrating familiarity with innovation and entrepreneurship skills, including customer discovery, market analysis, development planning, and communicating innovation; and gaining capability and confidence as innovators, problem solvers, and communicators, particularly in the medical device industry but transferable to any career path.
Units: 2

BME 580/RBE 580/ME 5205: Biomedical Robotics

This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussion of related literature. The course will culminate in a team project covering one or more of the primary course focus areas. Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

Units: 2

Prerequisites:

Linear algebra, ME/RBE 301 or equivalent.

CE/ME 5303: Applied Finite Element Methods in Engineering

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 533 or CE 524.

Units: 2

ME/CE 5303: Applied Finite Element Methods in Engineering

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 333 or CE 324.

Units: 2

ME/MFE/MTE 5420: Fundamentals of Axiomatic Design of Manufacturing Processes

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools. Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

Units: 2

ME/RBE 521: Legged Robotics

Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.

Units: 3

Recommended Background:

RBE 300, RBE 501.

ME/RBE 530: Soft Robotics

Soft robotics studies "intelligent" machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work.

Units: 2

Prerequisites:

Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

ME 501/RBE 501: Robot Dynamics

Foundations and principles of robot dynamics. Topics include system modeling including dynamical modeling of serial arm robots using Newton and Lagrange's techniques, dynamical modeling of mobile robots, introduction to dynamics-based robot control, as well as advanced techniques for serial arm forward kinematics, trajectory planning, singularity and manipulability, and vision-based control. In addition, dynamic simulation techniques will be covered to apply the concepts learned using realistic simulators. An end of term team project would allow students to apply mastery of the subject to real-world robotic platforms.

Units: 3

Prerequisites:

RBE 500 or equivalent

ME 513: Thermodynamics

Review of the zeroth, first and second laws of thermodynamics and systems control volume. Applications of the laws to heat engines and their implications regarding the properties of materials. Equations of state and introduction to chemical thermodynamics.

Units: 3

ME 514: Fluid Dynamics

This course is an introduction to graduate-level fluid dynamics. Specific learning outcomes include deriving and understanding the governing equations of fluid mechanics; applying basic equations of fluid motion to understand inviscid fluids, Newtonian fluids, and incompressible fluids; analyzing potential flows using stream functions and potential functions; deriving exact solutions of fluid equations for special flow cases; and introducing the concept of boundary layers and deriving similarity solutions for boundary layer equations. Students cannot receive credit for this course if they have received credit for AE/ME 5101 or AE/ME 5107.

Units: 3

Prerequisites:

undergraduate-level fluid dynamics.

ME 516: Heat Transfer

Review of governing differential equations and boundary conditions for heat transfer analysis. Multidimensional and unsteady conduction, including effects of variable material properties. Analytical and numerical solution methods. Forced and free convection with laminar and turbulent flow in internal and external flows. Characteristics of radiant energy spectra and radiative properties of surfaces. Radiative heat transfer in absorbing and emitting media. Systems with combined conduction, convection and radiation. Condensation, evaporation, and boiling phenomena.

Units: 3

Prerequisites:

Background in thermodynamics, fluid dynamics, ordinary and partial differential equations, and basic undergraduate physics

ME 543/MFE 520/MTE 520: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE521, MTE521 and ME521.

Units: 3

ME 550/BME 550: Tissue Engineering

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented.

Units: 3

Recommended Background:

A first course in biomaterials equivalent to ME/BME 4814 and a basic understanding of physiology and cell biology

ME 552/BME 552: Tissue Mechanics

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues, and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties and design of medical devices and prostheses.

Units: 3

Recommended Background:

A first course in biomechanics equivalent to ME/BME 4304.

ME 591: Graduate Seminar

Seminars on current issues related to various areas of mechanical engineering are presented by authorities in their fields. All full-time mechanical engineering students are required to register and attend.

Units: 0

ME 593: Special Topics

Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Department well in advance of the offering.

Units: 0

Prerequisites:

Consent of instructor

ME 598: Directed Research

For M.S. students wishing to gain research experience peripheral to their thesis topic, or for Ph.D. students wishing to gain research experience peripheral to their dissertation topic..

Units: 0

ME 599: Thesis Research

For masters students wishing to obtain research credit toward their thesis.

Units: 0

Prerequisites:

Consent of Thesis Advisor

ME 621: Dynamics and Signal Analysis

A laboratory-based course which applies Fourier and cepstral signal analysis techniques to mechanical engineering problems. The theory and application of the Fourier series, Fast Fourier Transform (FFT) and the cepstrum to the analysis of mechanical and acoustical systems is presented. Digital sampling theory, windowing, aliasing, filtering, noise averaging and deconvolution are discussed. Limitations of and errors in implementation of these techniques are demonstrated. Students will perform weekly experiments in the Structural Dynamics and Vibration Laboratory, which reinforce the theories presented in lectures. Application will include structures, acoustics, rotating machinery and cams.

Units: 3

ME 634: Holographic Numerical Analysis

Recent advances in holographic analysis of body deformations are discussed. Included in the course are topics covering sandwich holography, optoelectronic fringe interpolation technique, theory of fringe localization, use of projection matrices and the fringe tensor theory of holographic strain analysis. The application of interactive computer programs for holographic analysis of engineering and biological systems will be outlined. Lectures are supplemented by laboratory demonstrations and experiments.

Units: 3

Prerequisites:

Matrix algebra, vector calculus and consent of instructor.

ME 693: Advanced Special Topics

Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Department well in advance of the offering.

Units: 0

Prerequisites:

Consent of instructor

ME 698: Pre-Dissertation Research

Intended for doctoral students wishing to obtain dissertation-research credit prior to admission to candidacy.

Units: 0

Prerequisites:

Consent of Dissertation Advisor

ME 699: Dissertation Research

Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations.

Units: 0

Prerequisites:

Consent of Dissertation Advisor

ME 5000: Applied Analytical Methods in Engineering

The emphasis of this course is on the modeling of physical phenomena encountered in typical engineering problems, and on interpreting solutions in terms of the governing physics. In this manner, the course will expose students to a range of techniques that are useful to practicing engineers and researchers. Physical examples will be drawn from fluid mechanics, dynamics, stability problems, and structural mechanics. The course will introduce analytical techniques as they are required to study such phenomena. Depending on the examples chosen, the techniques covered may include partial differential equations, power series, Fourier series, Fourier integrals, including cases of sustained nonperiodic processes which require incorporating probabilistic approach into dynamics, Greens Functions, Sturm-Liouville theory and linear algebra. Students cannot receive credit for this course if they have taken either the Special Topics (ME 593A) version of the same course or ME 300.

Units: 2

Prerequisites:

differential equations at the undergraduate level.

ME 5001.: Applied Numerical Methods in Engineering

A study of important numerical and computational methods for solving engineering science problems. The course will include methods for solving linear and nonlinear equations, interpolation strategies, evaluating integrals, and solving ordinary and partial differential equations. Finite difference methods will be developed in full for the solution of partial differential equations. The course materials emphasize the systematic generation of numerical methods for elliptic, parabolic, and hyperbolic problems, and the analysis of their stability, accuracy, and convergence properties. The student will be required to write and run computer programs. Students cannot receive credit for this course if they have taken the Special Topics (ME 593M) version of the same course or ME 313.
Units: 2

ME 5104: Turbomachinery

This course is an introduction to the fluid mechanics and thermodynamics of turbomachinery for propulsion and power generation applications. Axial and centrifugal compressors will be discussed as well as axial and radial flow turbines. Analysis of the mean line flow in compressor and turbine blade rows and stages will be discussed. The blade-to-blade flow model will be presented and axisymmetric flow theory introduced. Three-dimensional flow, i.e. secondary flows, will also be discussed. Students cannot receive credit for this course if they have taken the Special Topics (ME 593H) version of the same course.
Units: 2

ME 5105: Renewable Energy

The course provides an introduction to renewable energy, outlining the challenges in meeting the energy needs of humanity and exploring possible solutions in some detail. Specific topics include: use of energy and the correlation of energy use with the prosperity of nations; historical energy usage and future energy needs; engineering economics; electricity generation from the wind; wave/ocean energy, geo-thermal and solar-thermal energy; overview of fuel cells, biofuels, nuclear energy, and solar-photovoltaic systems and their role and prospects; distribution of energy and the energy infrastructure; energy for transportation; energy storage.
Units: 2
Prerequisites:
ES3001, ES3004 or equivalents.

ME 5108: Introduction to Computational Fluid Dynamics

The course provides the theory and practice of computational fluid dynamics at an entry graduate level. Topics covered include: classification of partial differential equations (PDEs) in fluid dynamics and characteristics; finite difference schemes on structured grids; temporal discretization schemes; consistency, stability and error analysis of finite difference schemes; explicit and implicit finite differencing schemes for 2D and 3D linear hyperbolic, parabolic, elliptic, and non-linear PDEs in fluid dynamics; direct and iterative solution methods for algebraic systems. The course requires completion of several projects using MATLAB.
Units: 2

ME 5200: Mechanical Vibrations

The course provides fundamentals for vibration analysis of linear discrete and continuous dynamic systems, A vibrating system is first modeled mathematically as an initial value problem (IVP) or a boundary-initial value problem (BIVP) by the Newton-D'Alembert method and/or the Lagrange energy approach and then solved for various types of system. Explicit solutions for dynamic response of a linear single-degree-of-freedom (SDOF) system, both damped and undamped, is derived for free-vibration caused by the initial conditions and forced vibration caused by different excitations. Modal analysis is presented to solve for vibration response of both multi-degree-of-freedom (MDOF) systems and continuous systems with distributed parameters. As the basis of modal analysis, the natural frequencies and vibration modes of a linear dynamic system are obtained in advance by solving an associated generalized eigenvalue problem and the orthogonal properties of the vibration modes with respect to the stiffness and mass matrices are strictly proved. Computational methods for vibration analysis are introduced. Applications include but are not limited to cushion design of falling packages, vehicles traveling on a rough surface, multi-story building subjected to seismic and wind loading, and vibration analysis of bridges subjected to traffic loading. Students cannot receive credit for this course if they have taken the Special Topics (ME 593V) version of the same course or ME522.
Units: 2

ME 5202: Advanced Dynamics

Basic concepts and general principles of classical kinematics and dynamics of particles, systems of particles and rigid bodies are presented with application to engineering problems with complicated three-dimensional kinematics and dynamics. Derivation of the governing equations of motion using Principle of Virtual Work and Lagrange equations is described together with the direct Newton approach. Applications include: swings-effect and its use in engineering, illustrating in particular limit cycles and their stability and reversed-swings control of vibrations of pendulum; various examples of gyroscopic effects; and especially introductory rotordynamics including transverse vibrations (whirling) and potential instability of rotating shafts. Students cannot receive credit for this course if they have taken the Special Topics (ME 593D) version of the same course or ME 527.

Units: 2

ME 5204/RBE 510: Multi-Robot Systems

This course covers the foundation and principles of multi-robot systems. The course will cover the development of the field and provide an overview on different control architectures (deliberative, reactive, behavior-based and hybrid control), control topologies, and system configurations (cellular automata, modular robotic systems, mobile sensor networks, swarms, heterogeneous systems). Topics may include, but are not limited to, multi-robot control and connectivity, path planning and localization, sensor fusion and robot informatics, task-level control, and robot software system design and implementation. These topics will be pursued through independent reading, class discussion, and a course project. The course will culminate in a group project focusing on a collaborative/ cooperative multi-robot system. The project may be completed through simulation or hands-on experience with available robotic platforms. Groups will present their work and complete two professional-quality papers in IEEE format. Students cannot receive credit for this course if they have taken the Special Topics (ME 593S) version of the same course.

Units: 2

Prerequisites:

Linear algebra, differential equations, linear systems, controls, and mature programming skills, or consent of the instructor.

ME 5205/RBE 580: Biomedical Robotics

This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussionof related literature. The course will culminate in a team project covering one or more of the primary course focus areas.

Units: 2

Recommended Background:

Linear algebra, ME/RBE 301 or equivalent Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

ME 5220: Control of Linear Dynamical Systems

This course covers analysis and synthesis of control laws for linear dynamical systems. Fundamental concepts including canonical representations, the state transition matrix, and the properties of controllability and observability will be discussed. The existence and synthesis of stabilizing feedback control laws using pole placement and linear quadratic optimal control will be discussed. The design of Luenberger observers and Kalman filters will be introduced. Examples pertaining to aerospace engineering, such as stability analysis and augmentation of longitudinal and lateral aircraft dynamics, will be considered. Assignments and term project (if any) will focus on the design, analysis, and implementation of linear control for current engineering problems. The use of Matlab®/Simulink® for analysis and design will be emphasized.

Units: 2

Recommended Background:

Familiarity with ordinary differential equations, introductory control theory, fundamentals of linear algebra, and the analysis of signals and systems is recommended. Familiarity with Matlab® is strongly recommended.

ME 5221: Control of Nonlinear Dynamical Systems

Overview of stability concepts and examination of various methods for assessing stability such as linearization and Lyapunov methods. Introduction to various design methods based on linearization, sliding modes, adaptive control, and feedback linearization. Demonstration and performance analysis on engineering systems such as flexible robotic manipulators, mobile robots, spacecraft attitude control and aircraft control systems. Control synthesis and analysis is performed using Matlab®/Simulink®.

Units: 2

Prerequisites:

Familiarity with ordinary differential equations, introductory control theory at the undergraduate level, fundamentals of linear algebra. Familiarity with Matlab® is strongly recommended

ME 5225: Fiber Optical Sensors

This course is designed to introduce students to the field of fiber optics, with an emphasis on design and working principles of fiber optical sensors for mechanical, biological, and chemical measurements. Students will be able to learn the basic knowledge and working principles of optical fibers and fiber optical components, as well as practical design guidelines and applications of fiber optical sensing systems. The first half of the course will introduce the fundamentals of fiber optics, including working principles of optical fibers, single-mode and multimode fibers, properties of optical fibers, passive fiber optical devices, light sources, and optical detectors. The second half will focus on practical fiber optical sensors and sensing systems, including working principles of fiber optical sensors, intensity-based and interferometer-based fiber optical sensors, fiber Bragg gratings, and low-coherence fiber optical interferometers. Specifically, design and implementation of fiber optical sensors and sensing systems for strain and pressure measurements will be discussed in detail. Measurement characteristics and signal processing of fiber optical sensing systems for different applications will be introduced.

Units: 2

Recommended Background:

Undergraduate level stress analysis and wave fundamentals, such as ES 2502, PH 1140. Knowledge of vibrations such as ME 4506 is preferred but not required.

ME 5304: Laser Metrology and Nondestructive Testing

Demands for increased performance and efficiency of components in the nano/micro-, meso-, and macro-scales, impose challenges to their engineering design, study, and optimization. These challenges are compounded by multidisciplinary applications to be developed inexpensively in short time while satisfying stringent design objectives. As a consequence, effective quantitative engineering methodologies, such as optical techniques, are frequently used in the study and optimization of advanced components and systems. In this course, modern laser metrology techniques are discussed and their practical applications to solve problems, with emphasis on nondestructive testing (NDT), are illustrated with laboratory demonstrations. Topics covered include wave and Fourier optics, classic and holographic interferometry, speckle techniques, solid-state lasers, fiber optics, CCD cameras, computer vision, camera calibration methods, and image processing and data reduction algorithms as required in quantitative fringe analysis. Detail examples of nondestructive testing and coherent optical metrology in solid mechanics, vibrations, heat transfer, electromagnetics, and reverse engineering are given. Students are required to work on projects depending on their background and interests. Students cannot receive credit for this course if they have taken the Special Topics (ME 593J) version of the same course or ME 534.

Units: 2

Recommended Background:

mechanics, materials, physics, knowledge of a high-level computer programming language.

ME 5311/MTE 511: Structure and Properties of Engineering Materials

This course, (along with its companion course MTE 512 Properties and Performance of Engineering Materials), is designed to provide a comprehensive review of the fundamental principles of Materials Science and Engineering for incoming graduate students. In the first part of this 2-course sequence, the structure in materials ranging from the sub-atomic to the macroscopic including nano, micro and macromolecular structures will be discussed to highlight bonding mechanisms, crystallinity and defect patterns. Representative thermodynamic and kinetic aspects such as diffusion, phase diagrams, nucleation and growth and TTT diagrams will be discussed. Major structural parameters that effect of performance in materials including plastics, metallic alloys, ceramics and glasses will be emphasized. The principal processing techniques to shape materials and the effects of processing on structure will be highlighted. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594S).

Units: 2

Prerequisites:

senior or graduate standing or consent of the instructor.

ME 5312/MTE 512: Properties and Performance of Engineering Materials

The two introductory classes on materials science (MTE 511 and MTE 512) describe the structure-property relationships in materials. The purpose of this class is to provide a basic knowledge of the principles pertaining to the physical, mechanical and chemical properties of materials. The primary focus of this class will be on mechanical properties. The thermal, tensile, compressive, flexural and shear properties of metallic alloys, ceramics and glasses and plastics will be discussed. Fundamental aspects of fracture mechanics and viscoelasticity will be presented. An overview of dynamic properties such as fatigue, impact and creep will be provided. The relationship between the structural parameters and the preceding mechanical properties will be described. Basic composite theories will be presented to describe fiber-reinforced composites and nanocomposites. Various factors associated with material degradation during use will be discussed. Some introductory definitions of electrical and optical properties will be outlined. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594P).

Units: 2

Prerequisites:

senior or graduate standing or consent of the instructor.

ME 5313: Introduction to Nanomechanics

This course introduces students to nanomechanics. Topics covered include an introduction to mechanical systems, forces at the nano to atomic scales, cantilever theory, mechanics of 0D, ID and 2D nanomaterials, polymer chain nanomechanics, molecular recognition, wear friction and adhesion at the nanoscale, scale dependence of frictional resistance, nano-indentation, surface elasticity and viscoelasticity mapping, lubrication principles at the nanoscale, interfacial forces in confined fluids, mechanics of electrorheological and magnetic fluids.

Units: 2

Recommended Background:
ME 4875 or consent of Instructor.

ME 5314: Microsystems Technology

This course will build on the fundamentals of semiconductor manufacturing and its applications in micromechanical systems. Microsystems technology explores the science of miniaturization (the science of making small things). The course will discuss top-down and bottom-up manufacturing techniques, lithography, pattern transfer using additive and subtractive techniques, wet bulk micromachining, surface micromachining, LIGA and micromolding, scaling laws, and applications of miniaturized devices. Some examples of micro-devices such as accelerometers, pressure sensors, chemical sensors and biomedical sensors will be discussed.

Units: 2

ME 5356/MTE 556: Smart Materials

A material whose properties can respond to an external stimulus in a controlled fashion is referred to as a smart or intelligent material. These materials can be made to undergo changes modulus, shape, porosity, electrical conductivity, physical form, opacity, and magnetic properties based on an external stimulus. The stimuli can include temperature, pH, specific molecules, light, magnetic field, voltage and stress. These stimuli-sensitive materials can be utilized as sensors and as vehicles for the controlled delivery of drugs and other biomolecules in medical applications. Smart materials are also becoming important in other biological areas such as bio-separation, biosensor design, tissue engineering, protein folding, and microfluidics. The use of stimuli-sensitive materials is receiving increasing attention in the development of damage tolerant smart structures in aerospace, marine, automotive and earth quake resistant buildings. The use of smart materials is being explored for a range of applications including protective coatings, corrosion barriers, intelligent batteries, fabrics and food packaging. The purpose of this course is to provide an introduction to the various types of smart materials including polymers, ceramic, metallic alloys and composites. Fundamental principles associated with the onset of “smart” property will be highlighted. The principles of self-healable materials based on smart materials will be discussed. The application of smart materials in various fields including sensors, actuators, diagnostics, therapeutics, packaging and other advanced applications will be presented. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594X).

Units: 2

ME 5358/MTE 558: Plastics

This course will provide an integrated overview of the design, selection and use of synthetic plastics. The basic chemistry associated with polymerization and the structure of commercial plastics will be described. Various aspects of polymer crystallization and glass transition will be outlined. Salient aspects of fluid flow and heat transfer during the processing of plastics will be highlighted. Fundamentals of the diverse processing operations used to shape plastics and the resulting structures that develop after processing will be discussed. The mechanical behavior of plastics including elastic deformation, rubber elasticity, yielding, viscoelasticity, fracture and creep will be discussed. Plastic degradation and environmental issues associated with recycling and disposal of plastics will be examined. Typical techniques used in the analysis and testing of plastics will be described and a working knowledge of various terminologies used in commercial practice will be provided. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594A).

Units: 2

ME 5361/MTE 561: Mechanical Behavior and Fracture of Materials

The failure and wear-out mechanisms for a variety of materials (metals, ceramics, polymers, composites and microelectronics) and applications will be presented and discussed. Multi-axial failure theories and fracture mechanics will be discussed. The methodology and techniques for reliability analysis will also be presented and discussed. A materials systems approach will be used. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 593C/MTE 594C).

Units: 2

Prerequisites:

ES 2502 and ME 3023 or equivalent, and senior or graduate standing in engineering or science.

ME 5370/MTE 5841/MFE 5841: Surface Metrology

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science. Students cannot receive credit for this course if they have received credit for ME 5371/MTE 5843/MFE 5843 Fundamentals of Surface Metrology or the Special Topics (ME 593/MTE 594/MFE 594) version of Fundamentals of Surface Metrology.

Units: 3

ME 5371/MFE 5843/MTE 5843: Fundamentals of Surface Metrology

Surface Metrology is about measuring, characterizing, and analyzing surface topographies or textures. This course covers conventional and developing measurement and characterization of roughness. It emphasizes research and covers a wide variety of applications, including, adhesion, friction, fatigue life, mass transfer, scattering, wear, manufacturing, food science, wetting, physical anthropology, and archeology. Surface metrology has applications in practically all engineering disciplines and sciences. Research principles are applied to critical evaluations of research methods. Students learn multiscale methods for discovering correlations between processing, textures, and behavior , and for discriminating surface textures supposed to be different because of their performance or manufacture. Results support product and process design, and quality assurance. Students create detailed project proposals on topics of their choosing, including literature reviews, preparation and testing of surfaces, measurements, characterizations, and analyses. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594/MFE 594) version of this course, or for ME 5370/MTE 5841/MFE 5841 Surface Metrology.

Units: 2

ME 5380: Foundations of Elasticity

This course is suitable as an introductory graduate level course. Topics will be chosen from the following: three-dimensional states of stress; measures of strain; thick-walled cylinders, disks and spheres; plane stress and plane strain; thermoelasticity; Airy stress function; energy methods, and exact theory for torsion of noncircular cross sections. This course may be taken independent of ME 5302.
Units: 2

ME 5381: Applied Elasticity

This course is suitable as an introductory graduate level course. Topics covered will be chosen from the following: bending and shear stresses in unsymmetric beams; bending of composite beams; bending of curved beams; torsion of thin-walled noncircular cross sections; beams on elastic foundations; stress concentrations; failure criteria; stability of columns; and bending of plates. This course may be taken independent of ME 5301.
Units: 2

ME 5383/CE 514: Continuum Mechanics

This course covers the fundamentals of continuum mechanics at an introductory graduate level. Topics covered include: 1) Introduction: essential mathematics - scalars, vectors, tensors, and indicial notation; 2) Basics: three-dimensional states of stress, finite and infinitesimal measures strain, and principal axes; 3) Conservations laws: mass, linear momentum, angular momentum and energy; 4) Constitutive equations: ideal materials, Newtonian fluids, isotropy and anisotropy, elasticity and thermoelasticity, plasticity, and viscoelasticity; 5) Applications to classical problems and emerging topics in solid and fluid mechanics.
Units: 2
Recommended Background: undergraduate knowledge of strength of materials, fluid mechanics, and linear algebra.

ME 5385/MFE 5385/MTE 5385: Metal Additive Manufacturing

Additive Manufacturing (AM), popularly known as 3D printing, is a technique in which parts are fabricated in a layer-by-layer fashion. The focus of this course is on direct metal AM processes that are used in aerospace, automobile, medical, and energy industries. The objective of the course is to enable students to understand the working principles of various additive manufacturing processes, assess the suitability of metal AM processes for different designs and applications, apply process design concepts to metal AM processes via analytical and finite element modeling approaches, and have an introductory-level understanding of design for AM. Through the course project, students will have the opportunity to experience hands-on design, manufacturing, and characterization of additively manufactured materials, and will work in an interdisciplinary team of mechanical, materials, and manufacturing engineers. The economics of the manufacturing process will also be addressed, with an emphasis on determining the major cost drivers and discussing cost minimization strategies. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.
Units: 2

ME 5390/MTE 5390: Solar Cells

The objective of this course is to provide students with an understanding of the working principles, design, fabrication and characterization of established and emerging solar cell technologies. Students will be exposed to the electronic properties of semiconductor materials, which are the building blocks of solar cells, and the analysis of photo-generation and extraction of charges in these materials. The course will emphasize the influence of the atomic-, nano- and micro-scale structure of the materials on the solar cell performance. In addition, the challenges of economics and scalability that must be addressed to increase the deployment of solar cells will be discussed. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.

Units: 2

ME 5401: Computer-Aided Design and Geometric Modeling

This course covers topics in computer-aided geometric design and applications in mechanical engineering. The objectives of the course are to familiarize the students with complex geometric modeling and analytical techniques used in contemporary computer-aided design systems. Topics to be covered may include complex curve and surface generation, solid modeling, assembly and mechanism modeling, transformations, analytic geometry, offsets and intersections of complex shapes, graphics standards and data transfer, rendering techniques, parametric design and geometric optimization, numerical methods for geometric analysis and graphics design programming.

Units: 2

Prerequisites:

calculus, linear algebra, introductory computer programming, and ability to utilize a solid modeling CAD system. Students cannot receive credit for this course if they have taken the Special Topics (ME 593C) version of the same course or ME 545.

ME 5431/MFE 531: Computer Aided Manufacturing

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. Emphasis is placed on CAD/CAM integration. Topics include, part design specification and manufacturing quality, tooling and fixture design, and manufacturing information systems. This course includes a group term project. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (ME 593D/MFE 594D).

Units: 2

Prerequisites:

Background in manufacturing and CAD/CAM, e.g., ME 1800, ES 1310, ME 3820.

ME 5441/MFE 541: Design for Manufacturability

The problems of cost determination and evaluation of processing alternatives in the designmanufacturing interface are discussed. Approaches for introducing manufacturing capability knowledge into the product design process are covered. An emphasis is placed on part and process simplification, and analysis of alternative manufacturing methods based on such parameters as: anticipated volume, product life cycle, lead time, customer requirements, and quality yield. Lean manufacturing and Six-Sigma concepts and their influence on design quality are included as well. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE 594M).

Units: 2

ME 6108: Intermediate Computational Fluid Dynamics

The course presents computational methods for incompressible and compressible viscous flows at an intermediate level. Topics are chosen from: grid generation techniques; finite volume schemes; stability analysis; artificial viscosity; explicit and implicit schemes; flux-vector splitting; monotonic advection schemes; multigrid methods; particle-based simulation methods. Students who have received credit for AE/ME 3103 will not receive credit for AE/ME 6108.

Units: 2

Prerequisites:

fluid dynamics; an introductory course in numerical methods for partial differential equations; programming language experience)

ME 6201: Advanced Topics in Vibration

The course presents advanced topics in vibrations of machines and structures: dynamic stability analysis for linear nonconservative systems with applications to aeroelasticity and rotordynamics such as whirling of shafts with internal energy dissipation; introduction into theory of nonlinear and parametric vibrations in machines and structures; probabilistic approach in dynamics - analysis of random vibrations with applications to reliability evaluation in earthquake engineering, offshore engineering, etc. Use of random vibration analyses is illustrated for online condition monitoring for machines and structures (mechanical signature analysis), such as detecting instability and evaluating stability margin for a nonconservative system from its online measured signal. Introduction into general vibration theory makes the course self-contained (background in ME 522 preferable but not necessary). Students cannot receive credit for this course if they have taken the Special Topics (ME 593B) version of the same course.

Units: 2

MFE 520/MTE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

Units: 3

MFE 531/ME 5431: Computer Integrated Manufacturing

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. Emphasis is placed on CAD/CAM integration. Topics include, part design specification and manufacturing quality, tooling and fixture design, and manufacturing information systems. This course includes a group term project. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE 593D/MFE 594D

Units: 2

Prerequisites:

Background in manufacturing and CAD/CAM, e.g., ME 1800, ES 1310, ME 3820.)

MFE 541/ME 5441: Design for Manufacturability

The problems of cost determination and evaluation of processing alternatives in the designmanufacturing interface are discussed. Approaches for introducing manufacturing capability knowledge into the product design process are covered. An emphasis is placed on part and process simplification, and analysis of alternative manufacturing methods based on such parameters as: anticipated volume, product life cycle, lead time, customer requirements, and quality yield. Lean manufacturing and Six-Sigma concepts and their influence on design quality are included as well. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE594M).

Units: 2

MTE/ME 5847: Materials for Electrochemical Energy Systems

An introductory course on electrochemical engineering, fuel cells and batteries. With escalating oil prices and increasing environmental concerns, increasing attention is being paid to the development of electrochemical devices to replace traditional energy. Here several types of batteries and fuel cells will be discussed. Topics covered include: basic electrochemistry, lithium ion battery, proton exchange membrane fuel cell, solid oxide fuel cell, electrochemical method. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

Units: 2

Recommended Background:

ES2001 or equivalent.

MTE 511/ME 5311: Structure and Properties of Engineering Materials

This course, (along with its companion course MTE 512 Properties and Performance of Engineering Materials), is designed to provide a comprehensive review of the fundamental principles of Materials Science and Engineering for incoming graduate students. In the first part of this 2 course sequence, the structure in materials ranging from the sub-atomic to the macroscopic including nano, micro and macromolecular structures will be discussed to highlight bonding mechanisms, crystallinity and defect patterns. Representative thermodynamic and kinetic aspects such as diffusion, phase diagrams, nucleation and growth and TTT diagrams will be discussed. Major structural parameters that effect of performance in materials including plastics, metallic alloys, ceramics and glasses will be emphasized. The principal processing techniques to shape materials and the effects of processing on structure will be highlighted. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594S

Units: 2

Prerequisites:

senior or graduate standing or consent of the instructor.

MTE 512/ME 531: Properties and Performance of Engineering Materials

The two introductory classes on materials science (MTE 511 and MTE 512) describe the structure-property relationships in materials. The purpose of this class is to provide a basic knowledge of the principles pertaining to the physical, mechanical and chemical properties of materials. The primary focus of this class will be on mechanical properties. The thermal, tensile, compressive, flexural and shear properties of metallic alloys, ceramics and glasses and plastics will be discussed. Fundamental aspects of fracture mechanics and viscoelasticity will be presented. An overview of dynamic properties such as fatigue, impact and creep will be provided. The relationship between the structural parameters and the preceding mechanical properties will be described. Basic composite theories will be presented to describe fiber-reinforced composites and nanocomposites. Various factors associated with material degradation during use will be discussed. Some introductory definitions of electrical and optical properties will be outlined. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594P).

Units: 2

Prerequisites:

MTE 511 and senior or graduate standing or consent of the instructor

MTE 520/MFE 520/ME 543: Axiomatic Design of Manufacturing Processes

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability. This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

Units: 3

MTE 556/ME 5356: Smart Materials

A material whose properties can respond to an external stimulus in a controlled fashion is referred to as a smart or intelligent material. These materials can be made to undergo changes modulus, shape, porosity, electrical conductivity, physical form, opacity, and magnetic properties based on an external stimulus. The stimuli can include temperature, pH, specific molecules, light, magnetic field, voltage and stress. These stimuli-sensitive materials can be utilized as sensors and as vehicles for the controlled delivery of drugs and other biomolecules in medical applications. Smart materials are also becoming important in other biological areas such as bio-separation, biosensor design, tissue engineering, protein folding, and microfluidics. The use of stimuli-sensitive materials is receiving increasing attention in the development of damage tolerant smart structures in aerospace, marine, automotive and earth quake resistant buildings. The use of smart materials is being explored for a range of applications including protective coatings, corrosion barriers, intelligent batteries, fabrics and food packaging. The purpose of this course is to provide an introduction to the various types of smart materials including polymers, ceramic, metallic alloys and composites. Fundamental principles associated with the onset of "smart" property will be highlighted. The principles of self-healable materials based on smart materials will be discussed. The application of smart materials in various fields including sensors, actuators, diagnostics, therapeutics, packaging and other advanced applications will be presented. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594).

Units: 2

MTE 561/ME 5361: Mechanical Behavior and Fracture of Materials

The failure and wear-out mechanisms for a variety of materials (metals, ceramics, polymers, composites and microelectronics) and applications will be presented and discussed. Multi-axial failure theories and fracture mechanics will be discussed. The methodology and techniques for reliability analysis will also be presented and discussed. A materials systems approach will be used. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 593C/MTE 594C).

Units: 2

Prerequisites:

ES 2502 and ME 3023 or equivalent, and senior or graduate standing in engineering or science.

MTE 575/ME 4875: Introduction to Nanomaterials and Nanotechnology

This course introduces students to current developments in nanoscale science and technology. The current advance of materials and devices constituting of building blocks of metals, semiconductors, ceramics or polymers that are nanometer size (1-100 nm) are reviewed. The profound implications for technology and science of this research field are discussed. The differences of the properties of matter on the nanometer scale from those on the macroscopic scale due to the size confinement, predominance of interfacial phenomena and quantum mechanics are studied. The main issues and techniques relevant to science and technologies on the nanometer scale are considered. New developments in this field and future perspectives are presented. Topics covered include: fabrication of nanoscale structures, characterization at nanoscale, molecular electronics, nanoscale mechanics, new architecture, nano optics and societal impacts.

Units: 2

Recommended Background:

ES 2001 Introduction to Materials or equivalent

MTE 5390/ME 5390: Solar Cells

The objective of this course is to provide students with an understanding of the working principles, design, fabrication and characterization of established and emerging solar cell technologies. Students will be exposed to the electronic properties of semiconductor materials, which are the building blocks of solar cells, and the analysis of photo-generation and extraction of charges in these materials. The course will emphasize the influence of the atomic-, nano- and micro-scale structure of the materials on the solar cell performance. In addition, the challenges of economics and scalability that must be addressed to increase the deployment of solar cells will be discussed. Students cannot receive credit for this course if they have received credit for the Special Topics (ME 593/MTE 594) version of the same course.

Units: 2

RBE/ME 521: Legged Robotics

Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/ balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.

Units: 3

Recommended Background:

RBE 300, RBE 301.

RBE/ME 530: Soft Robotics
Soft robotics studies “intelligent” machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work.
Units: 2
Prerequisites:
Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

RBE 501/ME 501: Robot Dynamics
Foundations and principles of robot dynamics. Topics include system modeling including dynamical modeling of serial arm robots using Newton and Lagrange’s techniques, dynamical modeling of mobile robots, introduction to dynamics-based robot control, as well as advanced techniques for serial arm forward kinematics, trajectory planning, singularity and manipulability, and vision-based control. In addition, dynamic simulation techniques will be covered to apply the concepts learned using realistic simulators. An end of term team project would allow students to apply mastery of the subject to real-world robotic platforms.
Units: 3
Prerequisites:
RBE 500 or equivalent

Neuroscience

NEU 501: Neuroscience
In this course, students will develop an understanding of neurobiology at several levels, from the physiology of individual neurons, through the functioning of neural circuits, and finally to the behavior of neural systems such as vision, motion, and memory. Topics covered include spatial orientation and sensory guidance, neuronal control of motor output, neuronal processing of sensory information, sensorimotor integration, neuromodulation, circadian rhythms and cellular mechanisms of learning and memory Furthermore, students will learn about artificial intelligence and machine learning approaches to creating computational models of the brain using artificial neural networks and deep learning. The class will be based on lectures accompanied by in-class activities and will include weekly discussion of papers from the scientific literature. The class will focus on a guiding theme, such as neurotransmitter systems, with emphasis on research of human neurological problems, such as schizophrenia, addiction, and neurodegenerative disorders.
Units: 3

NEU 502: Neural Plasticity
Neuronal connections strengthen and weaken with learning, memory, or other events; a phenomenon called synaptic plasticity. In this course, we explore the underlying biological, biophysical and biochemical changes responsible for plasticity. This course covers the structure and organization of neuronal connections, the neurotransmitter receptors that line these structures, the signaling pathways that are mediated in synapses, the mechanical processes that underlie protraction and retraction, and the pharmacological agents that stimulate or block these changes. Students are required to have had an undergraduate level course in biology and biochemistry.
Units: 3

NEU 503: Computational Neuroscience
Computational neuroscience explores the brain at many different levels, from single cell activity, to small local network computation, to the dynamics of large neuronal populations across the brain. This course will introduce students to a multifaceted array of approaches that span biology, physics, mathematics and computer science as well as facilitate the integration of modeling (on both the single molecule and neuron level) and quantitative techniques to investigate neural activity at these different levels. Where possible, this course has a tripartite organization. First, the theory is presented from a text or journal article. Second, students read and critique a paper that uses the technique. Finally, simulations and/or problem sets are assigned to fix the knowledge learned in the course. Pertinent examples will be drawn from research done by WPI students and faculty.
Units: 3

NEU 504: Advanced Psychophysiology

This course will provide an in-depth understanding of what psychophysiology is and the common methods used to understand psychophysiological responses. Common psychophysiological methods will be discussed in-depth, such as sympathetic and parasympathetic nervous system, facial electromyography, electroencephalography (EEG), respiration, blood pressure, pulse rate, skin temperature, electrodermal responses, cortisol, and other neuroendocrine monitoring methods. The social, cognitive, emotional, and motivational responses to different psychological events will be explored in detail. Computational methods will be described from the fields of artificial intelligence, machine learning, and mobile computing for capturing, processing and discovering patterns in physiological and behavioral data. In addition, the course will examine how biofeedback works in educational, clinical, and experimental settings. Students may not receive credit for both PSY 2502 and NEU 504.
Units: 3

NEU 505: Brain-Computer Interaction

This course will explore the current state of brain sensing and its application to human-computer interaction research. This course covers brain function, sensing technology, machine learning methods, and applications of brain-computer interfaces in various domains. This course aims for students to (1) obtain the background to conduct research in brain-computer interaction and human-computer interaction; (2) understand the literature in the field of brain sensing for human-computer interaction research; (2) understand the various tools used in brain sensing, with a focus on functional near-infrared spectroscopy (fNIRS) research; (3) understand the steps required to use real-time brain sensing data as input to an interactive system; (4) understand the domains and contexts in which brain-computer interfaces may be effective; (5) understand the open questions and challenges in brain-computer interaction research today.
Units: 3

NEU 510: Neuroscience Seminar

(0 credits, pass/fail grading) This seminar provides an opportunity for students in the Neuroscience program to present their research work, as well as hear research presentations and talks from guest speakers.
Units: 0

NEU 590: Special Topics in Neuroscience

This course is intended to provide the students of the program a diverse selection of current relevant topics in neuroscience. Prerequisites will vary with topic.

Units: 3

NEU 596: Independent Study in Neuroscience

This course will allow a student to study a chosen topic in Neuroscience under the guidance of a faculty member affiliated with the Neuroscience Masters program. The student must produce a written report at the conclusion of the independent study.

Units: 3

NEU 597: Directed Research in Neuroscience

Directed research conducted under the guidance of a faculty member affiliated with the Neuroscience Program.

Units: 3

NEU 599: M.S. Thesis Research in Neuroscience

A Master's thesis in Neuroscience consists of a research and development project worth a minimum of 9 graduate credit hours advised by a faculty member affiliated with the Neuroscience Program. A thesis proposal must be approved by the Neuroscience Program Review Board and the student's advisor before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document and present the results to the Neuroscience faculty in a public presentation.

Units: 3

NEU 5900: Graduate Internship in Neuroscience

Graduate internship is carried out in cooperation with a sponsor or industrial partner. It must be overseen by a faculty member affiliated with the Neuroscience Program. The internship will involve development and practice of technical and professional skills and knowledge relevant to different areas of Neuroscience. At the completion of the internship, the student will produce a written report, and will present their work to core and affiliated Neuroscience faculty and internship sponsors.

Units: 3

Nuclear Science and Engineering

NSE 510: Introduction to Nuclear Science and Engineering

This introductory course provides an overview of the field of nuclear science and engineering as it relates to nuclear power and nuclear technologies. Fundamental concepts relevant to nuclear systems are introduced, including radioactivity, radiation interaction phenomena, chain reaction physics, and transport in engineering materials. Nuclear reactor physics and design concepts are introduced with focus on light water fission reactors. A survey of advanced nuclear technologies and applications is provided.

Units: 3

Prerequisites:

graduate or senior standing or consent of the instructor.

NSE 515: Radiation Biology

This course will introduce the student to fundamental concepts in radiation biology. Initially, theories will be developed concerning the effects of radiation exposure on basic biological systems, such as a virus or a cell. These theories will be based on our knowledge of radiation interaction mechanisms at the atomic/molecular level coupled with our knowledge of cell biology. Once developed, these theories will be compared against experimental observations and expanded to include cellular kinetic responses to radiation. Focus will then shift from the simple cell to more complex biological organisms. Ultimately, the student will be expected to appreciate the practical aspects and consequences of human radiation exposure and to properly apply this information in a radiation safety or medical physics environment.

Units: 3

NSE 520: Applied Nuclear Physics

This course introduces engineering and science students to the fundamental topics of nuclear physics for applications, basic properties of the nucleus, nuclear radiations, and radiation interactions with matter. The course is divided into four main sections: (1) introduction to elementary quantum mechanics, (2) nuclear and atomic structure, (3) nuclear decays and radiation, and (4) nuclear matter interactions and nuclear reactions.

Units: 3

Prerequisites:

Physics of mechanics and electrodynamics (PH 1110/11 and PH 1120/21) and mathematical techniques up to and including ordinary differential equations (MA 2031)

NSE 530: Health Physics

This course builds on fundamental concepts introduced in NSE 310 and applies them to key topics in health physics and radiation protection. Health physics topics include man-made and natural sources of radiation, dose, radiation biology, radiation measurement, and radiation safeguards. Radiation protection concepts are explored as they apply to existing and advanced nuclear power generators, including reactor safety, nuclear waste and byproducts, regulatory constraints, and accident case studies.

Units: 3

Prerequisites:

graduate standing or consent of the instructor

NSE 540: Nuclear Materials

This course applies fundamental materials science concepts to effects on materials in harsh nuclear environments. An overview is provided on environments, special nuclear materials, and constraints in materials selection. Relationships are developed between nuclear effects on crystal structure, microstructure, degraded material performance, and bulk properties of engineering and electronic materials. Case studies provide examples of enhancements induced my multiple harsh environments and mitigation through material design hardening.

Units: 3

Prerequisites:

ES 2001 or equivalent.

NSE 550: Reactor Design, Operations, and Safety

This course provides a systems engineering view of commercial nuclear power plant technology. Power plant designs and their evolutions are studied, ranging from early to modern generation light water reactors, as well as advanced designs families, such alternate moderator and breeder reactors. Critical aspects of conventional power reactor designs are explored in detail, including steam supply, reactor core, control, and protection systems. Plant operational characteristics are studied, including reactor dynamics, control, feedback, and fuel cycle management. Critical power plant safety aspects of the design and operations are explored and reinforced with lessons learned from major power generator accidents scenarios (including Three Mile Island, Chernobyl, and Fukushima Daiichi).

Units: 3

Prerequisites:

graduate standing or consent of the instructor

NSE 560: Nuclear Instrumentation

Students will be introduced to the theory and operation of general nuclear instrumentation such as x-ray production and detection, gamma ray detection, Geiger counters, scintillators, photomultiplier detectors, and nuclear magnetic resonance. Hands-on activities and training are emphasized.

Units: 3

NSE 570: Diagnostic Medical Physics

Students will be introduced to the fields of diagnostic medical imaging with a focus on the fundamental imaging physics. Basic concepts, including: matter and energy, x-ray production, and photon interactions, will lead to topics in x-ray generation, nuclear magnetic resonance, and sound-wave propagation. The course will then focus on the different diagnostic imaging modalities including X-ray radiography, Computed Tomography, Nuclear Magnetic Resonance, Gamma Scintillation, and ultrasound imaging.

Units: 3

NSE 580: Radiation Therapy Physics

Students will learn the theory, practice, and application of radiation oncology and therapy. Using the basic concepts of matter and energy, the production of x-rays, and photon interactions in tissue, the student will be introduced to linear accelerator (LINAC) physics, radiation treatment planning, and photon and electron dosimetry. In addition, this course will cover topics of current interest in radiation therapy such as: intensity-modulated radiation therapy, calibration of electron and photon beams, brachytherapy, hyper-fractionation therapy, and charged particle therapy.

Units: 3

NSE 585: Medical Ethics and Responsible Conduct

This material is intended to cover ethical issues in clinical medicine, scientific research, and in the professional conduct of the medical physicist. The term "ethics" is used here in the sense of a permissible standard of conduct for members of a profession.

Units: 1

NSE 595: Special Topics

Arranged by faculty affiliate to the Nuclear Science and Engineering program for individual or groups of students, these courses survey areas that are not covered by the regular NSE course offerings.

Units: 1

Prerequisites:

Consent of instructor

Physics

PH 500: Independent Study

Various specialized topics and/or research areas from one to two graduate students. Arranged individually with the faculty.

Units: 1

PH 511: Classical Mechanics I

Lagrangian formulation Kinematics and dynamics of rigid bodies. Small oscillations. Motion in non-inertial frames, Hamiltonian mechanics. Canonical transformations. Hamilton-Jacobi theory.

Units: 3

PH 514: Quantum Mechanics I

Schrodinger equation, potential wells and barriers, Hilbert space formulation of quantum mechanics and applications, Central potentials, hydrogen atom, isotropic oscillator, angular momentum and spin.

Units: 3

PH 515: Quantum Mechanics II

Time independent perturbation theory, variational method and WKB method, time-dependent perturbation theory, partial wave theory of scattering, integral approach to scattering theory and Born approximation.

Units: 3

PH 522: Thermodynamics and Statistical Mechanics

The laws of thermodynamics. Elements of kinetic theory. Ensemble theory: canonical, microcanonical, and grand canonical ensembles. Quantum statistical mechanics, Bose-Einstein and Fermi-Dirac statistics. Special topics in statistical mechanics.
Units: 3

PH 533: Advanced Electromagnetic Theory

Classical electrodynamics including boundary-value problems using Greens functions, Maxwell's equations, electromagnetic properties of matter, wave propagation and radiation theory.
Units: 3

PH 541: Mathematical Methods in Physics

The emphasis of the course is on mathematical techniques needed by physicists. The course covers functions of complex variable, special functions, Fourier and Laplace transforms, linear algebra and tensor analysis.
Units: 3

PH 544: Fundamentals of Photonics

Wave optics, Gaussian beams, photon optics, guided-wave optics, semiconductor optics (sources and detectors), interaction of photons with atoms.
Units: 3

PH 548: Fundamentals of Sensors

The course offers an overview of basic sensor physics and technologies to provide practical working knowledge of sensors. The course will include basic sensor operating principles, the physics of sensors, electrical interfacing to sensors, measurement principles, and applications. A wide range of sensors could be covered, such as temperature, photonic, acoustic, chemical, biological, electromagnetic, pressure, position and motion sensors. There will also be a laboratory component to the course.
Units: 3

PH 554: Solid State Physics

Phonons and specific heat of solids; electronic conductivity and band theory of solids; Fermi and Bose gases, Optical properties of materials. Magnetic interactions.
Units: 3

PH 561: Atomic Force Microscopy

Atomic force microscopes (AFMs) are instruments that allow three-dimensional imaging of surfaces with nanometer resolution and are important enabling tools for nanoscience and technology. The student who successfully completes this course will understand the functional principles of AFMs, be able to run one, and interpret the data that are collected. The recommended background for this course is a bachelors degree in science or engineering. Students who have successfully completed PH 2510, the undergraduate version of this course, may not earn credit for PH 561.
Units: 3

PH 562: Fundamentals of Biological Physics

The course will cover the fundamental concepts of biological physics. The main objective is to learn how to apply the principles of physics, methods of mathematical analysis and computational modeling to complex biological systems and develop a better understanding. The approach will be truly interdisciplinary, bringing concepts from statistical physics, classical mechanics, cell biology, chemistry and biochemistry. Topics covered include: biology by the numbers: time and length scales, mechanical and chemical equilibrium in the living cell, entropy in biology, two-state systems and cooperative binding, random walks and the structure of macromolecules, architecture of the cytoskeleton, biological membranes, modeling of fluids, statistical view of biological dynamics, life in crowded environments, rate equations and dynamics in the cell, dynamics of molecular motors.
Units: 3

PH 563: Introduction to Experimental Methods in Biophysics

The course will overview the biophysical experimental techniques which are used in the study of the structure and function of biological systems at the cellular and molecular level. The main objectives are to understand the principles of most common biophysical technics and to learn essential skills to perform lab research in biophysics. Topics covered include: light microscopy, super-resolution microscopy, image processing, electron microscopy, x-ray diffraction and protein structure determination, NMR, spectroscopy, calcium measurements, resonance energy transfer, patch-clamp, optical tweezers, rheological characterization of soft materials, molecular force measurements, proportional-integral-derivative automation, protein expression, and design of DNA plasmid. Students will gain hands-on experience on cutting-edge biophysical techniques and will receive training on data collection, data analyzation, and scientific report writing.

Units: 3

PH 571: Biophysics/ Soft Condensed Matter Journal Club

Students interested in Biophysics/ Soft Condensed Matter read journal articles, prepare presentations and give short talks, engage in critical discussion, and provide feedback to fellow students. The objectives of the course are for students to learn about current topics in the broad area Biophysics/ Soft Condensed Matter and biotechnology and to improve their professional skills.

Units: 1

Recommended Background:

A bachelor's degree in science, technology, engineering, or mathematics.

PH 572: Nanoscience Journal Club

Students interested in nanoscience read journal articles, write abstracts, give short talks, engage in critical discussion, and provide feedback to fellow students. The objectives of the course are for students to learn about current topics in nanoscience and nanotechnology and to improve their professional skills.

Units: 1

PH 580: Graduate Seminar

Students attend Physics Colloquia by WPI faculty and invited scientists on current research topics in different areas of physics. They discuss results and ideas presented in those talks. In addition, students give presentations on their research or on problems of current interest to physics community. The course therefore will provide opportunities for students to develop their presentation skills, broaden their perspectives and provide networking opportunities. All full-time physics graduate students are required to register and attend.

Units: 0

PH 585: Scientific Writing and Proposal Development

This course will cover key elements of writing successful grant or fellowship proposals, as well as manuscripts. The topics that will be covered will include project development, identification of funding agencies or journals, proposal and manuscript writing and editing, as well as aspects of the submission and review process. Students will be expected to develop a proposal, and participate in reviews. Students are expected to complete this course prior to taking the Ph.D. Qualifying Exam in Physics.

Units: 1

Recommended Background:

A bachelor's degree in science, technology, engineering, or mathematics.

PH 597: Special Topics

Arranged by physics faculty for individual or groups of students, these offerings cover topics that are not covered by the regular Physics course offerings. Exact course descriptions are posted by the faculty in advance of the offering.

Units: 1

PH 598: Directed Research

A directed and coherent program of research that, in most cases, will eventually lead to thesis or dissertation research. This is also used for Directed Research Rotation (for 3 credit hours) for first year students who have not yet taken the Qualifying Examination in order to explore the available research opportunities.

Units: 0

PH 599: M.S. Thesis Research

Each student will work under the supervision of a member of the department on the thesis research for their Master of Science in Physics degree.

Units: 0

Prerequisites:

Consent of advisor

PH 699: Ph.D. Dissertation

Can be taken any time after passing the Physics Qualifying Examination but required in the last semester for the writing and defending of the Ph.D. dissertation.

Units: 0

Prerequisites:

Consent of advisor

PH 798: Comprehensive Written Examination

Comprehensive Written Examination prepared, administered and evaluated by the Physics Department Graduate Committee (PDGC).

Units: 0

Recommended Background:

Student should be enrolled in the Physics or Applied Physics Ph.D. program.

PH 799: Ph.D. Qualifying Examination

Students are required to write and defend an original research proposal before a committee representative of the area of their specialization, approved and appointed by the Physics Department Graduate Committee (PDGC).

Units: 0

Recommended Background:

Student should be enrolled in the Physics Graduate program, seeking a Ph.D. degree.

Physics for Educators

MPE 510: Classical Mechanics

Broad coverage emphasizing interconnections of a mechanical description of the universe utilizing both algebraic and calculus language at a level appropriate for secondary school educators. Topics include: vectors and vector manipulation to describe motion, Newton's laws of motion; work and energy concepts; energy and momentum conservation laws; models of forces and interactions; generalized coordinates and momentum; overview of Lagrangian and Hamiltonian formulations.

Units: 2

MPE 520: Electrodynamics

Broad coverage at the appropriate level emphasizing interconnections of the electromagnetic interactions in the universe utilizing both algebraic and calculus language at a level appropriate for secondary school educators. Topics include: electro and magnetostatics and dynamics, boundary-value problems; Maxwell's equations; overview of electromagnetic properties of matter and wave propagation (radiation).

Units: 2

MPE 530: Modern Physics

Broad coverage of the three central areas of modern physics that emphasize the wonder and interconnections at the conceptual level appropriate for secondary school educators. Topics include: Quantum Physics (postulates, Schrodinger and Dirac formalisms, implications and interpretations), Special and Introduction to General Relativity (the four-vector, space-time, invariants, time dilation and length contraction), and Thermo/ Statistical Physics (macroscopic variables, equation of state, state functions, response functions, microscopic variables, statistical approach, ensembles, the partition function).

Units: 2

MPE 540: Differential Equations in Nature

Emphasizes connections and interconnections with the mechanical, electromagnetic, and modern areas as well as mathematical areas of oscillations, waves, and optics utilizing differential equations at a level appropriate for secondary school educators. Topics include: Free, damped, and driven-damped oscillations, waves, Doppler Effect, optics, interference and diffraction. Examples are drawn from a wide range of physical phenomena to illustrate each concept. To develop this content, homogeneous and non-homogeneous differential equations of the first and second order will be employed. Thick contextual meaning will be drawn to support mathematical foundation and vice versa to allow for deeper "authentic" learning.

Units: 2

MPE 550: Computational Methods in Physics

Topics are chosen to illustrate various numerical techniques useful for educators and students to illustrate physics concepts and develop a sense of physical intuition through simulations and modeling. It is not intended to be a course on numerical methods; rather it will be aimed at the application of numerical methods to physical models. Various programming languages/ platforms are utilized in each example to highlight the general nature and to provide choices matching students programming backgrounds.

Units: 2

MPE 560: Experimental Methods in Physics

Hands-on methods of physically testing concepts and models of the universe. Technology is utilized but general methods accessible to barely outfitted lab environments are stressed. Topics covered are in a series of subject units, the physical principles underlying the phenomena to be observed and the basis for the measurement techniques employed is reviewed. Principles and uses of standard laboratory instruments (oscilloscopes, meters for frequency, time, electrical and other quantities, lock-in amplifiers, etc.) are stressed. In addition to systematic measurement procedures and data recording, strong emphasis is placed on processing of the data, preparation and interpretation of graphical presentations, and analysis of precision and accuracy, including determination and interpretation of best value, measures of error and uncertainty, linear best fit to data, and identification of systematic and random errors. Preparation of high-quality experiment reports is also emphasized. Representative experiment subjects are: mechanical motions and vibrations; free and driven electrical oscillations; electric fields and potential; magnetic materials and fields; electron beam dynamics; optics; diffractiongrating spectroscopy; radioactive decay and nuclear energy measurements.

Units: 2

MPE 572: Physics Research Experience for Teachers

Provides educators with hands-on research experience either in the research programs in Physics at WPI or other venues but under the oversight of the physics faculty. The goal is to support the active involvement of educators in research in order to translate their research experience into new classroom activities and build long term collaborative relationships between the researcher(s), educator(s), and potentially the educator (s') students. Research activities can range from experimental to theoretical to computational and can involve multiple educators and/or their students with some expectation that the activity may lead to a publication.

Units: 3

MPE 574: Physics for Citizens and Leaders

Emphasizes physics concepts and connections to society. Educators will explore and understand the important connections between society and the relevant physics concepts and their context. The goal is for the educator to be able to apply critical thinking of the application of physics to important societal issues. Topics can range from energy options, climate change, technology assessment and risk, ethical use of science.

Units: 3

MPE 576: Physics in Popular Culture

Covers myths and misconceptions of physics in popular culture (i.e., movies, books, TV, web, etc.). The goal of this independent study is for the educator to be able to identify how the representation of physics in popular media perpetuates important myths and misconceptions that impact reasoning and critical thinking, sometimes in a profoundly negative way. Emphasis is placed on utilizing these representations as teaching/learning moments for the specific relevant physical concepts.

Units: 3

Psychology

PSY/SEME 501: Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research.

Units: 3

Prerequisites:

None

PSY/SEME 502: Learning Environments in Education

In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences.

Units: 3

Prerequisites:

None

PSY/SEME 503: Research Methods for the Learning Sciences

This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters.

Units: 3

Prerequisites:

SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion

PSY/SEME 504: Meta-Cognition, Motivation, and Affect

This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic.

Units: 3

Prerequisites:

None

PSY 505: Advanced Methods and Analysis for the Learning and Social Sciences

This course covers advanced methods and analysis for the learning and social sciences, focusing on contemporary modeling and inference methods for the types of data generated in these forms of research. This course will enable students to choose, utilize, and make inferences from analytical metrics that are appropriate and/ or characteristic to these domains, properly accounting for the characteristic forms of structure found in data typically collected for research in the learning and social sciences. Some of the topics covered will include ROC analysis and the use of A for assessing student models, learning curve and learning factor analysis, social network and dyad analysis, and appropriate methods for tracking student learning and behavior in longitudinal data. Readings will be drawn from original source materials (e.g. journal articles and academic book chapters).

Units: 3

Prerequisites:

PSY503, Research Methods for the Learning Sciences, comparable course, or instructor discretion.

PSY 506: Learning and Creativity

This course will cover selected topics related to learning and creativity—including measurement, memory, semantic networks, sleep, analogies, problem-solving, divergent thinking, and insight moments. Students will critically review journal articles and other forms of media to gain a better understanding of the processes involved in learning and creative cognition. Students will also learn about prominent theories of learning and creativity and identify ways to utilize these frameworks to improve education and student experiences in the classroom.

Units: 3

PSY 507: Applied Multi-Level Modeling

The purpose of this course is to examine current issues in learning sciences and education and introduce students to the analysis of nested data structures (e.g., students within classrooms). Longitudinal or repeated measures data can also be thought of as clustered data with measurement occasions nested within subjects. This course will focus on understanding the hierarchical (generalized) linear models and their assumptions, as well as practical aspects of developing models to address research questions and interpreting the findings. This course emphasizes practical, hands-on development, analysis and interpretation of hierarchical linear models. Readings will be drawn from book chapters on multilevel modeling and journal articles that utilize national longitudinal data sets to answer questions about student learning. The lab portion of this course will provide students with opportunities to learn and apply hierarchical linear modeling, mediation, and moderation to longitudinal data using two computer programs (HLM and SPSS). Students who received credit for SS 590: Applied Multi-Level Modeling in 2018 or 2015 cannot also take PSY 507 for credit.
Units: 3

PSY 590: Special Topics in Psychological Science

(1-3 credits) This course provides an opportunity for graduate students to learn about a special topic within Psychological Science. This course may be repeated for different topics.

SEME/PSY 501: Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research.
Units: 3
Prerequisites:
None

SEME/PSY 502: Educational Learning Environments

In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences.
Units: 3
Prerequisites:
None

SEME/PSY 503: Research Methods for the Learning Sciences

This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters.
Units: 3
Prerequisites:
SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion

SEME/PSY 504: Meta-Cognition, Motivation, and Affect

This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic.

Units: 3

Prerequisites:

None

Robotics Engineering

BME 520/RBE 520: Biomechanics and Robotics

This course introduces Biomechanics and Robotics as a unified subject addressing living and man-made "organisms". It draws deep connections between the natural and the synthetic, showing how the same principles apply to both, starting from sensing, through control, to actuation. Those principles are illustrated in several domains, including locomotion, prosthetics, and medicine. The following topics are addressed: Biological and Artificial sensors, actuators and control, Orthotics Biomechanics and Robotics, Prosthetic Biomechanics and Robotics: Artificial Organs and Limbs, Rehabilitation Robotics and Biomechanics: Therapy, Assistance and Clinical Evaluation, Human-Robot Interaction and Robot Aided Living for Healthier Tomorrow, Sports, Exercise and Games: Biomechanics and Robotics, Robot-aided Surgery, Biologically Inspired Robotics and Micro- (bio) robotics, New Technologies and Methodologies in Medical Robotics and Biomechanics, Neural Control of Movement and Robotics Applications, Applied Musculoskeletal Models and Human Movement Analysis. This course meshes physics, biology, medicine and engineering and introduce students to subject that holds a promise to be one of the most influential innovative research directions defining the 21st century.

Units: 3

Recommended Background:

foundation of physics, linear algebra and differential equations; basic programming skills e.g. using MATLAB, undergraduate level biomechanics, robotics

BME 580/RBE 580/ME 5205: Biomedical Robotics

This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussion of related literature. The course will culminate in a team project covering one or more of the primary course focus areas. Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

Units: 2

Prerequisites:

Linear algebra, ME/RBE 301 or equivalent.

CS/RBE 526: Human-Robot Interaction

This course focuses on human-robot interaction and social robot learning, exploring the leading research, design principles and technical challenges we face in developing robots capable of operating in real-world human environments. The course will cover a range of multidisciplinary topics, including physical embodiment, mixed-initiative interaction, multi-modal interfaces, human-robot teamwork, learning algorithms, aspects of social cognition, and long-term interaction. These topics will be pursued through independent reading, class discussion, and a final project.
Units: 3
Prerequisites:
Mature programming skills and at least undergraduate level knowledge of Artificial Intelligence, such as CS 4341. No hardware experience is required

CS/RBE 549: Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images.
Units: 3
Prerequisites:
CS 534, CS 543, CS 545, or the equivalent of one of these courses

ME/RBE 521: Legged Robotics

Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.
Units: 3
Recommended Background:
RBE 300, RBE 501.

ME/RBE 530: Soft Robotics

Soft robotics studies “intelligent” machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work.
Units: 2
Prerequisites:
Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

ME 501/RBE 501: Robot Dynamics

Foundations and principles of robot dynamics. Topics include system modeling including dynamical modeling of serial arm robots using Newton and Lagrange’s techniques, dynamical modeling of mobile robots, introduction to dynamics-based robot control, as well as advanced techniques for serial arm forward kinematics, trajectory planning, singularity and manipulability, and vision-based control. In addition, dynamic simulation techniques will be covered to apply the concepts learned using realistic simulators. An end of term team project would allow students to apply mastery of the subject to real-world robotic platforms.
Units: 3
Prerequisites:
RBE 500 or equivalent

RBE/CS 549: Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images.
Units: 3
Prerequisites:
CS 534, CS 543, CS 545, or the equivalent of one of these courses

RBE/ME 521: Legged Robotics

Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.

Units: 3

Recommended Background:

RBE 300, RBE 301.

RBE/ME 530: Soft Robotics

Soft robotics studies "intelligent" machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work.

Units: 2

Prerequisites:

Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

RBE 500: Foundations of Robotics

Fundamentals of robotics engineering. Topics include forward and inverse kinematics, velocity kinematics, introduction to dynamics and control theory, sensors, actuators, basic probabilistic robotics concepts, fundamentals of computer vision, and robot ethics. In addition, modular robot programming will be covered, and the concepts learned will be applied using realistic simulators.

Units: 3

Prerequisites:

Differential Equations (MA 2051 or equivalent), Linear Algebra (MA 2071 or equivalent) and the ability to program in a high-level language

RBE 501/ME 501: Robot Dynamics

Foundations and principles of robot dynamics. Topics include system modeling including dynamical modeling of serial arm robots using Newton and Lagrange's techniques, dynamical modeling of mobile robots, introduction to dynamics-based robot control, as well as advanced techniques for serial arm forward kinematics, trajectory planning, singularity and manipulability, and vision-based control. In addition, dynamic simulation techniques will be covered to apply the concepts learned using realistic simulators. An end of term team project would allow students to apply mastery of the subject to real-world robotic platforms.

Units: 3

Prerequisites:

RBE 500 or equivalent

RBE 502: Robot Control

This course demonstrates the synergy between the control theory and robotics through applications and provides an in-depth coverage of control of manipulators and mobile robots. Topics include linearization, state space modeling and control of linear and nonlinear systems, feedback control, Lyapunov stability analysis of nonlinear control systems, set-point control, trajectory and motion control, compliance and force control, impedance control, adaptive robot control, robust control, and other advanced control topics. Course projects will emphasize simulation and practical implementation of control systems for robotic applications.

Units: 3

Prerequisites:

RBE 500 or equivalent, Linear algebra; Differential equations; Linear systems and control theory as in ECE 504 or consent of the instructor

RBE 510/ME 5204: Multi-Robot Systems

This course covers the foundation and principles of multi-robot systems. The course will cover the development of the field and provide an overview on different control architectures (deliberative, reactive, behavior-based and hybrid control), control topologies, and system configurations (cellular automata, modular robotic systems, mobile sensor networks, swarms, heterogeneous systems). Topics may include, but are not limited to, multi-robot control and connectivity, path planning and localization, sensor fusion and robot informatics, task-level control, and robot software system design and implementation. These topics will be pursued through independent reading, class discussion, and a course project. The course will culminate in a group project focusing on a collaborative/ cooperative multi-robot system. The project may be completed through simulation or hands-on experience with available robotic platforms. Groups will present their work and complete two professional-quality papers in IEEE format.

Units: 2

Prerequisites:

Linear algebra, differential equations, linear systems, controls, and mature programming skills, or consent of the instructor.) Students cannot receive credit for this course if they have taken the Special Topics (ME 593S) version of the same course.

RBE 526/CS 526: Human-Robot Interaction

This course focuses on human-robot interaction and social robot learning, exploring the leading research, design principles and technical challenges we face in developing robots capable of operating in real-world human environments. The course will cover a range of multidisciplinary topics, including physical embodiment, mixed-initiative interaction, multi-modal interfaces, human-robot teamwork, learning algorithms, aspects of social cognition, and long-term interaction. These topics will be pursued through independent reading, class discussion, and a final project.

Units: 3

Prerequisites:

Mature programming skills and at least undergraduate level knowledge of Artificial Intelligence, such as CS 4341. No hardware experience is required.) RBE 595 (Synergy of Human & Robot) and the RBE/CS 526 (Human-Robot Interaction) courses are equivalent. A student cannot take and get credit for both courses.

RBE 533: Smart Materials & Actuation

This hands on course covers smart materials and actuation, with an emphasis on electroactive polymer (EAP) based materials and actuators, such as contractile EAPs, dielectric elastomers (DEAs), and ion-polymer metal composites (IPMCs). Piezoelectric materials and shape memory alloys (SMAs) are included in the course, as well as pneumatic actuation. Because smart materials and electroactivity are relatively new fields, the course involves literature reviews. Each team project will involve two different types of smart materials, where at least one smart material is electroactive. For the team projects, the class will be organized into groups, ensuring that each group had a mixture of different disciplines to promote lively discussion. Two papers will be required, one as a literature review and one about aspects of the team project. Much of the theory and applied research is yet to be done with smart materials, so this is a very creative course that implements design into the projects, which can include biomimicry.

Units: 3

RBE 550: Motion Planning

Motion planning is the study of algorithms that reason about the movement of physical or virtual entities. These algorithms can be used to generate sequences of motions for many kinds of robots, robot teams, animated characters, and even molecules. This course will cover the major topics of motion planning including (but not limited to) planning for manipulation with robot arms and hands, mobile robot path planning with non-holonomic constraints, multi-robot path planning, high-dimensional sampling-based planning, and planning on constraint manifolds. Students will implement motion planning algorithms in open-source frameworks, read recent literature in the field, and complete a project that draws on the course material. The PR2 robot will be available as a platform for class projects. Physical robot platforms will be available for class projects.

Units: 3

Prerequisites:

Undergraduate Linear Algebra, experience with 3D geometry, and significant programming experience.

RBE 594: Capstone Project Experience in Robotics Engineering

This project-based course integrates robotics engineering theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Robotics Engineering curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Robotics Engineering profession. The project will include substantial analysis and/or design and conclude with a written report and a public presentation.

Units: 3

Prerequisites:

Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that students will have completed most or all of the coursework within their plan of study before undertaking the capstone project

RBE 595: Special Topics

Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular Robotics Engineering course offerings. Exact course descriptions are disseminated by the Robotics Engineering Program well in advance of the offering.

Units: 3

Prerequisites:

Consent of instructor

RBE 596: Robotics Engineering Practicum

This practicum provides an opportunity to put into practice the principles studied in previous courses. It will generally be conducted off campus and will involve real-world robotics engineering. Overall conduct of the practicum will be supervised by a WPI RBE faculty member; an on-site liaison will direct day-to-day activity. For a student from industry, an internship may be sponsored by his or her employer. The project must include substantial analysis and/or design related to Robotics Engineering and will conclude with a substantial written report. A public oral presentation must also be made, to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison and one additional WPI faculty member. This committee will verify successful completion of the internship.

Units: 3

Prerequisites:

Consent of practicum faculty advisor

RBE 597: Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests.

Units: 3

Prerequisites:

B.S. in CS, ECE, ME, RBE or equivalent and consent of advisor

RBE 598: Directed Research

For M.S. or Ph.D. students wishing to gain research experience peripheral to their thesis topic, M.S. students undertaking a capstone design project, or doctoral students wishing to obtain research credit prior to admission to candidacy. For Directed Research to count as the Masters capstone requirement you must take 3 credits and include substantial analysis and/ or design and conclude with a written report and a public presentation.
Units: 3
Prerequisites:
Consent of an RBE affiliated research advisor

RBE 599: Thesis Research

For masters students wishing to obtain research credit toward the thesis.
Units: 3
Prerequisites:
Consent of thesis advisor

RBE 699: Dissertation Research

For Ph.D. students wishing to obtain a research credit towards the dissertation.
Units: 3
Prerequisites:
Consent of research advisor.

STEM for Educators

CS/SEME 565: User Modeling

User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user.
Units: 3
Prerequisites:
Knowledge of probability

CS/SEME 566: Graphical Models for Reasoning Under Uncertainty

This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one.
Units: 3
Prerequisites:
CS 534 Artificial Intelligence or permission of the instructor

CS/SEME 567: Empirical Methods for Human-Centered Computing

This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research.

Units: 3

Prerequisites:

MA 511 Applied Statistics for Engineers and Scientists or permission of instructor

CS/SEME 568: Artificial Intelligence for Adaptive Educational Technology

Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system.

Units: 3

Prerequisites:

CS 534 Artificial Intelligence or permission of the instructor

MME/SEME 524-25: Probability, Statistics and Data Analysis I, II

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills: • Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena. • Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized. • Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data. • Design of experiments and sampling studies - the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

Units: 4

MME 592/SEME 602: Project Preparation (Part of a 3-Course Sequence with Mme 594 and Mme 596)

Students will research and develop a mathematical topic or pedagogical technique. The project will typically lead to classroom implementation; however, a project involving mathematical research at an appropriate level of rigor will also be acceptable. Preparation will be completed in conjunction with at least one faculty member from the Mathematical Sciences Department and will include exhaustive research on the proposed topic. The course will result in a detailed proposal that will be presented to the MME Project Committee for approval; continuation with the project is contingent upon this approval.
Units: 2

MME 594/SEME 604: Project Implementation

Students will implement and carry out the project developed during the project preparation course. Periodic contact and/or observations will be made by the project advisor (see MME 592 Project Preparation) in order to provide feedback and to ensure completion of the proposed task. Data for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.
Units: 2

MME 596/SEME 606: Project Analysis and Report

Students will complete a detailed statistical analysis of any data collected during the project implementation using techniques from MME 524-525 Probability, Statistics, and Data Analysis. The final report will be a comprehensive review of the relevant literature, project description, project implementation, any statistical results and conclusions. Project reports will be subject to approval by the MME Project committee and all students will be required to present their project to the mathematical sciences faculty. Course completion is contingent upon approval of the report and satisfactory completion of the presentation.
Units: 2

PSY/SEME 501: Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research.
Units: 3
Prerequisites:
None

PSY/SEME 502: Learning Environments in Education

In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences.
Units: 3
Prerequisites:
None

PSY/SEME 503: Research Methods for the Learning Sciences

This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters.
Units: 3
Prerequisites:
SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion

PSY/SEME 504: Meta-Cognition, Motivation, and Affect

This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic.

Units: 3

Prerequisites:

None

SEME/CS 565: User Modeling

User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user.

Units: 3

Prerequisites:

Knowledge of probability

SEME/CS 566: Graphical Models for Reasoning Under Uncertainty

This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one.

Units: 3

Prerequisites:

CS 334 Artificial Intelligence or permission of the instructor

SEME/CS 567: Empirical Methods for Human-Centered Computing

This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research.

Units: 3

Prerequisites:

MA 311 Applied Statistics for Engineers and Scientists or permission of instructor

SEME/CS 568: Artificial Intelligence for Adaptive Educational Technology

Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system.

Units: 3

Prerequisites:

CS 534 Artificial Intelligence or permission of the instructor

SEME/MME 524-25: Probability, Statistics and Data Analysis I, II

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills: • Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena. • Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized. • Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data. • Design of experiments and sampling studies — the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

Units: 2

SEME/PSY 501: Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research.
Units: 3
Prerequisites:
None

SEME/PSY 502: Educational Learning Environments

In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences.
Units: 3
Prerequisites:
None

SEME/PSY 503: Research Methods for the Learning Sciences

This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters.
Units: 3
Prerequisites:
SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion

SEME/PSY 504: Meta-Cognition, Motivation, and Affect

This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic.
Units: 3
Prerequisites:
None

SEME 562: Issues in Education

This course is about the theory and the practice of formative assessment. The practice will involve bringing those theories to life in the classroom. Participants will be required to actively implement the formative assessment cycle in their own teaching. Online tools that facilitate the formative assessment process will be used by the teachers. One such tool that will be required is ASSISTments. Participants will decide what data to collect evaluate and analyze. They will analyze the data in this class and with their students. They will examine their own instruction by videotaping themselves and sharing their experiences with the group. Participants will go through these steps repeatedly during the course. Participants will be required to synthesize and critique course materials through written documents and formal and informal presentations.
Units: 3

System Dynamics

SD 550: System Dynamics Foundation: Managing Complexity

Why do some businesses grow while others stagnate or decline? What causes oscillation and amplification - the so called “bullwhip” - in supply chains? Why do large scale projects so commonly over overrun their budgets and schedules? This course explores the counterintuitive dynamics of complex organizations and how managers can make the difference between success and failure. Students learn how even small changes in organizational structure can produce dramatic changes in organizational behavior. Real cases and computer simulation modeling combine for an in-depth examination of the feedback concept in complex systems. Topics include: supply chain dynamics, project dynamics, commodity cycles, new product diffusion, and business growth and decline. The emphasis throughout is on the unifying concepts of system dynamics.
Units: 3

SD 551: Modeling and Experimental Analysis of Complex Problems

This course deals with the hands on detail related to analysis of complex problems and design of policy for change through building models and experimenting with them. Topics covered include: slicing complex problems and constructing reference modes; going from a dynamic hypothesis to a formal model and organization of complex models; specification of parameters and graphical functions; experimentations for model understanding, confidence building, policy design and policy implementation. Modeling examples will draw largely from public policy agendas.
Units: 3
Prerequisites:
SD 550 System Dynamics Foundation: Managing Complexity

SD 552: System Dynamics for Insight

The objective of this course is to help students appreciate and master system dynamics’ unique way of using of computer simulation models. The course provides tools and approaches for building and learning from models. The course covers the use of molecules of system dynamics structure to increase model building speed and reliability. In addition, the course covers recently developed eigenvalue-based techniques for analyzing models as well as more traditional approaches.
Units: 3
Prerequisites:
SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems

SD 553: Model Analysis and Evaluation Techniques

This course focuses on analysis of models rather than conceptualization and model development. It provides techniques for exercising models, improving their quality and gaining added insights into what models have to say about a problem. Five major topics are covered: use of subscripts, achieving and testing for robustness, use of numerical data, sensitivity analysis, and optimization/calibration of models. The subscripts discussion provides techniques for dealing with detail complexity by changing model equations but not adding additional feedback structure. Robust models are achieved by using good individual equation formulations and making sure that they work together well though automated behavioral experiments. Data, especially time series data, are fundamental to finding and fixing shortcomings in model formulations. Sensitivity simulations expose the full range of behavior that a model can exhibit. Finally, the biggest section, dealing with optimization and calibration of models develops techniques for both testing models against data and developing policies to achieve specified goals. Though a number of statistical issues are touched upon during the course, only a basic knowledge of statistics and statistical hypothesis testing is required.
Units: 3
Prerequisites:
SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems, or permission of the instructor.

SD 554: Real World System Dynamics

In this course students tackle real-world issues working with real managers on their most pressing concerns. Many students choose to work on issues in their own organizations. Other students have select from a number of proposals put forward by managers from a variety of companies seeking a system dynamics approach to important issues. Students experience the joys (and frustrations) of helping people figure out how to better manage their organizations via system dynamics. Accordingly the course covers two important areas: consulting (i.e. helping managers) and the system dynamics standard method - a sequence of steps leading from a fuzzy “issue area” through increasing clarity and ultimately to solution recommendations. The course provides clear project pacing and lots of support from the instructors and fellow students. It is recommend that students take SD 552 Real World System Dynamics toward the end of their system dynamics coursework as it provides a natural transition from coursework to system dynamics practice.

Units: 3

Prerequisites:

SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems.

SD 556: Strategic Modeling and Business Dynamics

The performance of firms and industries over time rarely unfolds in the way management teams expect or intend. The purpose of strategic modeling and business dynamics is to investigate dynamic complexity by better understanding how the parts of an enterprise operate, fit together and interact. By modeling and simulating the relationships among the parts we can anticipate potential problems, avoid strategic pitfalls and take steps to improve performance. We study a variety of business applications covering topics such as cyclicality in manufacturing, market growth and capital investment. The models are deliberately small and concise so their structure and formulations can be presented in full and used to illustrate principles of model conceptualization, equation formulation and simulation analysis. We also review some larger models that arose from real-world applications including airlines, the oil industry, the chemicals industry and fast moving consumer goods. Students work with selected business policy problems based on generic structures discussed in the lessons.

Units: 3

Prerequisites:

SD 550 System Dynamics Foundation: Managing Complexity

SD 557: Latent Structures, Unintended Consequences, and Policy

This course addresses policy resilience and unintended consequences arising out of actions that are not cognizant of the latent structure causing the problem. An attempt is made to identify the generic systems describing such latent structures. The latent structures discussed include a selection from capacity constraining and capacity enabling systems, resource allocation, and economic cycles of various periodicities. Problems discussed in lessons include pests, gang violence, terrorism, political instability, professional competence in organizations, urban decay, and economic growth and recessions. Students work with selected public policy problems relevant to the generic latent structures discussed in the course.

Units: 3

Prerequisites:

SD 550 System Dynamics Foundation: Managing Complexity, SD 551 Modeling and Experimental Analysis of Complex Problems

SD 558: Introduction to Agent-Based Modeling

The purpose of this course is to provide students with an introduction to the field of agent-based computer simulation modeling in the social sciences. The course begins with an outline of the history of the field, as well as of the similarities and differences between agent-based computer simulation modeling and system dynamics computer simulation modeling. An important goal of the course is to provide students with guidelines for deciding when it is preferable to apply agent-based modeling, and when it is preferable to apply system dynamics modeling, to a particular problem. Through a series of example models and homework exercises students are introduced to the software that is used in the course. Generally speaking, as the course progresses students will be introduced to increasingly complicated agent-based models and exercises so that their modeling skills will grow. The goal is to increase students' modeling skills so that they will eventually be able to create their own agent-based models from scratch. The remainder of the course is devoted to examining models of socioeconomic phenomena that reside within two broad categories of agent-based models: cellular automata models and multi-agent models. Along the way the cross-category, cross-disciplinary, principles of agent-based modeling (micro-level agents following simple rules leading to macro-level complexity, adaptation, evolving structure, emergence, non-ergodicity) are emphasized.

Units: 3

SD 560: Strategy Dynamics

This course provides a rigorous set of frameworks for designing a practical path to improve performance, both in business and noncommercial organizations. The method builds on existing strategy concepts, but moves substantially beyond them, by using the system dynamics method to understand and direct performance through time. Topics covered include: strategy, performance and resources; resources and accumulation; the 'Strategic Architecture'; resource development; rivalry and the dynamics of competition; strategy, policy and information feedback; resource attributes; intangible resources; strategy, capabilities and organization; industry dynamics and scenarios. Case studies and models are assigned to students for analysis.

Units: 3

SD 561: Energy and Environmental Dynamics

This course helps students develop understanding and proficiency in system dynamics simulation of energy and environmental problems. The majority of the content is devoted to case studies that focus on energy, water and environmental problems. Major business applications deal with boom and bust in power plant construction and a similar pattern of boom and bust in real-estate construction. The text used is: Ford, Andrew. 2009. Modeling the Environment, 2nd Edition. Island Press. The book's website (http://www.wsu.edu/^forda/AA2nd.html) provides model files, background on the case studies and a wide variety of extra exercises. For example, Students interested in water resource management can simulate the complex tradeoffs in the management of large river basins; students interested in water quality can experiment with models of accelerated eutrophication of fresh water lakes. A highlight of SD 561 is a class project. One option is to select one of the more challenging sets of exercises from the book (or the book's website). Such a project is often the best way to conclude SD561 for students who are new to system dynamics. The other option is to improve one of the models from the book or the website. This option is usually best for students with previous course work in system dynamics. Their project report will explain why their simulations are an improvement on the published simulations. And they will explain whether the conclusions from their modeling reinforce or contradict the conclusions from the book.

Units: 3

Prerequisites:

SD 550 or permission of the instructor.

SD 562: Project Dynamics

This course will introduce students to the fundamental dynamics that drive project performance, including the rework cycle, feedback effects, and inter-phase "knock-on" effects. Topics covered include dynamic project problems and their causes: the rework cycle and feedback effects, knock-on effects between project phases; modeling the dynamics: feedback effects, schedule pressure and staffing, schedule changes, inter-phase dependencies and precedence; strategic project management: project planning, project preparation, risk management, project adaptation and execution cross project learning; multi-project issues. A simple project model will be created, and used in assignments to illustrate the principles of "strategic project management." Case examples of different applications will be discussed.

Units: 3

Prerequisites:

SD 550 System Dynamics Foundation: Managing Complexity.

SD 565: Macroeconomic Dynamics

There are three parts to this course. The first acquaints a student with dynamic macroeconomic data and the stylized facts seen in most macroeconomic systems. Characteristics of the data related to economic growth, economic cycles, and the interactions between economic growth and economic cycles that are seen as particularly important when viewed through the lens of system dynamics will be emphasized. The second acquaints a student with the basics of macroeconomic growth and business cycle theory. This is accomplished by presenting well-known models of economic growth and instability, from both the orthodox and heterodox perspectives, via system dynamics. The third part attempts to enhance a students ability to build and critique dynamic macroeconomic models by addressing such topics as the translation of difference and differential equation models into their equivalent system dynamics representation, fitting system dynamics models to macroeconomic data, and evaluating (formally and informally) a model's validity for the purpose of theory selection.

Units: 3

Prerequisites:

SD 550 System Dynamics Foundation: Managing Complexity.

SD 590: Special Topics

Systems Engineering

SYS 501: Concepts of Systems Engineering

Systems Engineering is a multifaceted discipline, involving human, organizational, and various technical variables that work together to create complex systems. This course is an introduction and overview of the methods and disciplines that systems engineers use to define, develop, and deploy systems. It includes specific integrated examples, projects, and team building exercises to aid in understanding and appreciating fundamental principles. Topics covered include; Introduction to Systems Engineering; Requirements Development; Functional Analysis and Requirements Allocation; System Architecture and System Design; Integration, Verification and Validation; Trade Studies; Systems Analysis, Modeling and Simulation; Specialty Engineering; Risk Management; and Technical Planning and Management.

Units: 3

Prerequisites:

an undergraduate degree in engineering or science, or permission of the instructor

SYS 502: Business Practices

This course introduces students to the business aspects of Systems Engineering (SE) and is designed to help SE professionals integrate Systems Engineering concepts into a professional business practice environment and to improve systems engineers' understanding fundamental business practices and their relationship to systems engineering. This course will cover how to prepare and evaluate professional quality business plans, project budgets, financial proposals, timelines and technical outlines. This course will also cover topics such as working with stakeholders; understanding competitive advantage and perceived value of systems engineering; various roles of systems engineers from a business practices perspective; contracting for systems engineering services, how systems engineers impact and are impacted by the various corporate operating divisions, and how to ensure quality control. The course will consist of lectures, case studies, class projects and student presentations.
Units: 3

SYS 510: Systems Architecture and Design

This course will study and contrast various important architectural frameworks, representations, tools, and methodologies in order to provide scalable and flexible approaches for enterprises operating in dynamic and complex environments. Enterprise-level system architecting tools will be discussed and demonstrated. At a minimum, the DoDAF, FEAF, Zachman, and TOGAF architectural frameworks will be discussed in depth. Other topics will include analysis of architectural alternatives to meet physical and logical objectives and providing information and systems assurance in an environment that takes people, processes, and technology into account. Modeling tools such as UML/SysML and the use of model-driven architectures will be presented. Validation of the architecture with stakeholders will be discussed. Methods of identifying risks and opportunities associated with the architectural choice will be explored. Practical examples will be included for illustration.
Units: 3
Prerequisites:
SYS 501 Concepts of Systems Engineering or another introductory course in Systems Engineering

SYS 511: Systems Integration, Verification and Validation

This course examines the use of Systems Engineering principles and best practices with respect to systems and systems-of-systems verification and validation (V&V). V&V processes, activities and methods as they apply across the product lifecycle will be examined. Case studies, papers and exercises will be used to examine the success and failure of verification, validation and test processes. Course topics include 1) How early systems engineering activities and solution sets affect integration, verification, validation and test; 2) V&V activities relative to product development phases; 3) Modeling quality, cost, time and risk; 4) Testing and non-testing methods; 5) V&V planning, execution and reporting; 6) Systems integration; and 7) V&V of critical and complex systems.
Units: 3
Prerequisites:
SYS 501 Concepts of Systems Engineering

SYS 512: Requirements Engineering

Requirements drive system definition and development. Properly managed requirements contribute to project success, while poorly defined and poorly managed requirements often lead to project failure. Modern systems are demanding even more attention to proper requirements definition and management. This course provides processes, techniques, and best practices necessary to develop and manage requirements in todays complex environments.
Units: 3
Prerequisites:
SYS 501 Concepts of Systems Engineering. Formerly SYS 579R

SYS 520: System Optimization

This course covers both the principles and practices of system optimization. The course includes both traditional mathematical treatments of optimization (including linear programming, non-linear programming, integer programming, stochastic methods such as Monte-Carlo methods, multi-objective system optimization, data envelope analysis) and practical, hands-on application with many real-world examples and student projects/ exercises. Qualitative as well as quantitative approaches will be discussed. The course begins with an introduction and definitions of system, optimization, and system optimization. It then proceeds to explain the traditional mathematical tools and models used in system optimization including location, allocation, scheduling, and blending models as well as sensitivity analysis and network models. Optimized design is covered next. The course will conclude with several multi-objective optimization problems. Student projects and real-world examples will be heavily emphasized. A technical undergraduate degree (B.A. or B.S. or equivalent) is a prerequisite for this course.

Units: 3

Prerequisites:

SYS 501

SYS 521: Model-Based Systems Engineering

Model-based systems engineering (MBSE) formalizes the practice of systems engineering through the use of models. This course is intended to answer the why, what and how of MBSE and provides background and motivation for transitioning from a document centric approach to a model-based approach to systems engineering. The course provides a foundation for MBSE by introducing SysML as a descriptive language for modeling systems and a method for applying SysML to support the specification, architecture design, and analysis of complex systems. The course also introduces other important aspects of implementing MBSE, including organizational and project planning considerations. The course includes a combination of slide presentations to introduce the fundamentals, coupled with class exercises and a class project to help the student grasp the fundamentals. A modeling tool is expected to be used for the class project.

Units: 3

Prerequisites:

SYS 501 Concepts of Systems Engineering.

SYS 540: Introduction to Systems Thinking

Systems Thinking provides an arsenal of tools that enable program managers and systems engineers to better identify, understand, and control systems, and to improve their performance. In this course, we will study system identification and delineation, causal loops and feedback, system leverage points, delays and oscillations, mental models and unintended consequences, emergent properties, patterns, events, and self-organization, and use these tools to improve the performance of engineering, biological, business, and complex social systems. We will explore great system failures, how they might have been avoided, and how we can learn from them in developing and participating in current systems. Finally, we will learn how systems thinking explains the conflicting behavior of individuals, departments, businesses, and countries.

Units: 3

SYS 579: Special Topics

Units: 3

SYS 585: Systems Engineering Capstone Experience

One of the central priorities in WPI's educational philosophy is the application of academic skills and knowledge to real-world problems. The capstone project represents a substantive evaluation and application of coursework covered in the program. Students are encouraged to select projects with practical significance for the advancement of their company's competitive position as well as their own personal development. The project is administered, advised, and evaluated by WPI as part of the learning experience, but students are encouraged to seek mentorship from experienced colleagues in the Systems Engineering profession. The presence of or degree of participation from a mentor is made at the discretion of the student or the organization sponsoring the program.
Units: 3
Prerequisites:
SYS 501 Concepts of Systems Engineering

SYS 596A and SYS 596B: Graduate Seminars

The graduate seminar series will be presented by recognized experts in various fields of Systems Engineering and related disciplines. All SE Ph.D. students are required to take two offerings of the SE seminar course. Each offering will be graded Pass/Fail.
Units: 3

SYS 597: Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Independent study students will work under the direct supervision of a WPI ECE, ME or CS faculty member.
Units: 3

SYS 598: Directed Research

Directed research students will work under the direct supervision of a WPI ECE, ME or CS faculty member on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required.
Units: 3

SYS 599: Thesis

Units: 3
Prerequisites:
Accepted to Systems Engineering M.S. degree program.

SYS 699: Ph.D. Dissertation

Reserved for Ph.D. candidate research. Approval of the Ph.D. research advisor is required.
Units: 0

Writing (WR) and Rhetoric (RH)

WR 593: Special Topics in Writing and Communication

The purpose of this course is to offer opportunities to graduate students to explore and develop their skills in writing and communication. The course content and format vary to suit the interests and needs of the faculty and students. Topics may include technical writing, science writing, health communication, public understanding of science, design of communication, and communicating risk and ethics in technology design. Contact the Humanities and Arts Department or the Professional Writing Program for current topic offerings.
Units: 3