

2018-19 Bulletin

School of Engineering & Applied Science Graduate Programs



Washington University in St. Louis

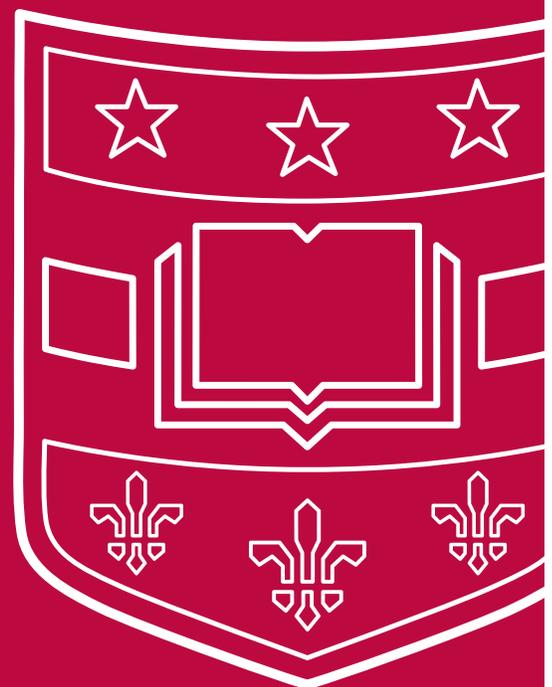


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About This Bulletin

The graduate and professional bulletins are the catalogs of programs, degree requirements and policies of the following schools of Washington University in St. Louis: Architecture & Urban Design; Art; Arts & Sciences; Engineering & Applied Science; Law; Medicine; and Social Work & Public Health.

The *University College Bulletin* is the catalog of University College, the professional and continuing education division of Arts & Sciences at Washington University in St. Louis. The catalog includes programs, degree requirements, course descriptions, and pertinent university policies for students earning a degree through University College.

The 2018-19 bulletins are entirely online but may be downloaded in PDF format for printing. Individual pages may be downloaded in PDF format using the "Download This Page as a PDF" option on each page. To download a full PDF, please choose from the following:

- Architecture & Urban Design (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_grad_architecture.pdf)
- Art (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_grad_art.pdf)
- Arts & Sciences (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_graduate_school.pdf)
- Engineering & Applied Science (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_grad_engineering.pdf)
- Law (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_law.pdf)
- Medicine (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_medicine.pdf)
- Social Work & Public Health (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_brownschool.pdf)
- University College (undergraduate and graduate) (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2018-19_university_college.pdf)

The degree requirements and policies in the *2018-19 Bulletin* apply to students entering Washington University during the 2018-19 academic year.

Every effort is made to ensure that the information, applicable policies and other materials presented in the *Bulletin* are accurate and correct as of the date of publication (October 16, 2018). Washington University reserves the right to make changes at any time without prior notice. Therefore, the electronic version of the *Bulletin* may change from time to time without notice. The governing document at any given time is the then-current version of the *Bulletin*, as published online, and then-currently applicable policies and information are those contained in that *Bulletin*.

For the most current information about available courses and class scheduling, visit WebSTAC (<https://acadinfo.wustl.edu>). Please email questions concerning the *Bulletin* to the Bulletin editor (bulletin_editor@wustl.edu).

For more graduate and professional programs, please visit the following website:

- Olin Business School (<http://olin.wustl.edu>)

About Washington University in St. Louis

Who We Are Today

Washington University in St. Louis, a medium-sized, independent university, is dedicated to challenging its faculty and students alike to seek new knowledge and greater understanding of an ever-changing, multicultural world. The university is counted among the world's leaders in teaching and research, and draws students from all 50 states, the District of Columbia, Guam, Puerto Rico and the Virgin Islands. Students and faculty come from more than 100 countries around the world.

The university offers more than 90 programs and almost 1,500 courses leading to bachelor's, master's and doctoral degrees in a broad spectrum of traditional and interdisciplinary fields, with additional opportunities for minor concentrations and individualized programs. For more information about the university, please visit the University Facts (<http://wustl.edu/about/facts>) page of our website.

Enrollment by School

For enrollment information (<https://wustl.edu/about/university-facts/#students>), please visit the University Facts page of our website.

Committed to Our Students: Mission Statement

Washington University's mission is to discover and disseminate knowledge, and protect the freedom of inquiry through research, teaching and learning. Washington University creates an environment to encourage and support an ethos of wide-ranging exploration. Washington University's faculty and staff strive to enhance the lives and livelihoods of students, the people of the greater St. Louis community, the country and the world.

Our goals are:

- to welcome students, faculty and staff from all backgrounds to create an inclusive community that is welcoming, nurturing and intellectually rigorous;
- to foster excellence in our teaching, research, scholarship and service;
- to prepare students with attitudes, skills and habits of lifelong learning and leadership thereby enabling them to be productive members of a global society; and
- to be an institution that excels by its accomplishments in our home community, St. Louis, as well as in the nation and the world.

To this end we intend:

- to judge ourselves by the most exacting standards;
- to attract people of great ability from diverse backgrounds;
- to encourage faculty and students to be bold, independent and creative thinkers;
- to provide an exemplary, respectful and responsive environment for living, teaching, learning and working for present and future generations; and
- to focus on meaningful measurable results for all of our endeavors.

Trustees & Administration

Board of Trustees

Please visit the Board of Trustees website (<http://boardoftrustees.wustl.edu>) for more information.

University Administration

In 1871, Washington University co-founder and then-Chancellor William Greenleaf Eliot sought a gift from Hudson E. Bridge, charter member of the university's Board of Directors, to endow the chancellorship. Soon it was renamed the "Hudson E. Bridge Chancellorship."

Led by the chancellor, the officers of the university administration (<http://wustl.edu/about/leadership>) are detailed on the university website.

Academic Calendar

The academic calendar of Washington University in St. Louis is designed to provide an optimal amount of classroom instruction and examination within a manageable time frame, facilitating our educational mission to promote learning among both students and faculty. Individual schools, particularly our graduate and professional schools, may have varying calendars due to the nature of particular fields of study. Please refer to each school's website for more information.

Fall Semester 2018

Date	Day	Description
August 27	Monday	Classes begin
September 3	Monday	Labor Day holiday
October 13-16	Saturday-Tuesday	Fall Break
November 21-25	Wednesday-Sunday	Thanksgiving Break
December 7	Friday	Last day of classes
December 10-19	Monday-Wednesday	Reading and Exams

Spring Semester 2019

Date	Day	Description
January 14	Monday	Classes begin
January 21	Monday	Martin Luther King Jr. holiday
March 10-16	Sunday-Saturday	Spring Break
April 26	Friday	Last day of classes
April 29 - May 8	Monday-Wednesday	Reading and Exams
May 17	Friday	Commencement

Summer Semester 2019

Date	Day	Description
May 20	Monday	First Summer Session begins
May 27	Monday	Memorial Day holiday
July 4	Thursday	Independence Day holiday
August 15	Thursday	Last Summer Session ends

Washington University recognizes the individual student's choice in observing religious holidays that occur during periods when classes are scheduled. Students are encouraged to arrange with their instructors to make up work missed as a result of religious observance, and instructors are asked to make every reasonable effort to accommodate such requests.

Campus Resources

Student Support Services

Cornerstone: The Learning Center is located on the ground floor of Gregg House on the South 40, and it is the hub of academic support at Washington University in St. Louis. We provide undergraduate students with assistance in a variety of forms. Most services are free, and each year more than 2,000 students participate in one or more of our programs. For more information, visit the Cornerstone website (<http://cornerstone.wustl.edu>) or call 314-935-5970. The three teams housed within Cornerstone:

- **Academic Mentoring Programs** offer academic support in partnership with the academic departments in a variety of forms. Academic mentoring programs are designed to support students in their course work by helping them develop the lifelong skill of "learning how to learn" and by stimulating their independent thinking. Programs include: course-specific, weekly structured study groups facilitated by highly trained peer leaders; course-specific weekly walk-in sessions facilitated by academic mentors in locations, at times and in formats convenient for the students. Cornerstone also offers individual consulting/coaching for

academic skills such as time management, study skills, note taking, accessing resources, etc. Other services include fee-based graduate and professional school entrance preparation courses.

- **Disability Resources** supports students with disabilities by fostering and facilitating an equal access environment for the Washington University community of learners. Disability Resources partners with faculty and staff to facilitate academic and housing accommodations for students with disabilities on the Danforth Campus. Students enrolled in the School of Medicine should contact their program's director. Please visit the Disability Resources website (<http://cornerstone.wustl.edu/disability-resources>) or contact Cornerstone: The Learning Center at 314-935-5970 for more information.
- **TRiO: Student Support Services** is a federally funded program that provides customized services for undergraduate students who are low-income, the first in their family to go to college, and/or have a documented disability. Services include academic coaching, academic peer mentoring, cultural and leadership programs, summer internship assistance, and post-graduation advising. First-year and transfer students are considered for selection during the summer before entering their first semester. Eligible students are encouraged to apply when notified, as space in this program is limited.

Office for International Students and Scholars. If a student is joining the university from a country other than the United States, this office can assist that individual through its orientation programs, by issuing certificates of eligibility (visa documents), and by offering special services for non-native English speakers in the English Language Programs. In addition, the office provides personal and cross-cultural counseling and arranges social, cultural and recreational activities that foster international understanding on campus.

The Office for International Students and Scholars is located in the Stix International House at 6470 Forsyth Boulevard and on the Medical School campus in the Mid Campus Center (MCC Building), 4590 Children's Place, Room 2043. For more information, visit the Office for International Students and Scholars website (<http://oiss.wustl.edu>) or call 314-935-5910.

Medical Student Support Services. For information about Medical Student Support Services, please visit the School of Medicine website (<https://medicine.wustl.edu>).

Relationship and Sexual Violence Prevention (RSVP) Center. The Relationship and Sexual Violence Prevention (RSVP) Center offers free and confidential services including 24/7 crisis intervention, counseling services, resources, support, and prevention education for all Danforth students. The RSVP Center operates from a public health model, utilizing trauma-informed practices to address the prevalent issues of relationship and sexual violence. Our goal in supporting impacted students is

to foster post-traumatic growth and resilience to better ensure academic retention and success. Our prevention efforts call for community engagement to engender an intolerance of violence and an active stance to challenge issues that perpetuate such a culture. Learn more at the RSVP Center website (<https://rsvpcenter.wustl.edu>).

WashU Cares. WashU Cares assists the university in handling situations involving the safety and well-being of Danforth Campus students. As such, WashU Cares is committed to fostering student success and campus safety through a proactive, collaborative, and systematic approach to the identification, intervention, and support of students of concern while empowering all university community members to create a culture of caring. If you are concerned about the physical or mental well-being of a student, please file a WashU Cares (<https://washucares.wustl.edu>) report.

The Writing Center. The Writing Center, a free service, offers writing advice to all Washington University undergraduate and graduate students. Tutors will read and discuss any kind of work in progress, including student papers, senior theses, application materials, dissertations and oral presentations. The Writing Center staff is trained to work with students at any stage of the writing process, including brainstorming, developing and clarifying an argument, organizing evidence, and improving style. Rather than editing or proofreading, tutors will emphasize the process of revision and teach students how to edit their own work. Appointments (<http://writingcenter.wustl.edu>) are preferred and can be made online.

The Writing Center is located in Olin Library on level one.

Student Health Services, Danforth Campus

The Habif Health and Wellness Center, formerly known as Student Health Services, provides medical and mental health care for undergraduate and graduate students. Habif staff members include licensed professionals in Medical Services, Mental Health Services, and Health Promotion Services. Please visit us in Dardick House on the South 40, or visit the Habif Health and Wellness Center website (<http://shs.wustl.edu>) for more information about each of our services and staff members.

Hours:

Monday, Tuesday and Thursday 8 a.m.-6 p.m.

Wednesday 10 a.m.-6 p.m.

Friday 8 a.m.-5 p.m.

Saturday 9 a.m.-1 p.m.

A nurse answer line is available to answer any medical questions a student may have when Habif is closed. For after-hours care, please call: 314-935-6666.

Medical Services staff members provide care for the evaluation and treatment of an illness or injury, preventive health care and health education, and nutrition, physical therapy, travel medicine

and women's health services. Habif Health and Wellness Center providers are considered in-network and are participating members of the Washington University in St. Louis Physician's Network. Any condition requiring specialized medical services will be referred to an appropriate community specialist. Habif accepts most health insurance plans and will be able to bill the plan according to plan benefits when care is accessed at Habif. The student health insurance plan requires a referral any time care is not provided at Habif. Call 314-935-6666 or visit our website to schedule an appointment (<http://shs.wustl.edu>) for medical care, including allergy injections prescribed by your allergist, health consultations, for HIV or other STD testing, or for immunizations.

Appointments also are available for assessment, treatment and referral for students who are struggling with substance abuse.

The Habif Health and Wellness Center pharmacy is available to all Washington University students and their dependents who participate in the student health insurance plan. The pharmacy accepts most prescription insurance plans; please check with the pharmacist to see if your prescription plan is accepted at the pharmacy.

The Habif Health and Wellness Center lab provides full laboratory services. Approximately 20 tests can be performed in the lab. The remainder of all testing that is ordered by Habif is completed by LabCorp. LabCorp serves as our reference lab and is on the student health insurance plan as a preferred provider. This lab can collect any test ordered by our providers or by outside providers.

All incoming students must provide proof of immunization for two measles, mumps, rubella vaccines after the age of one year old. (A titer may be provided in lieu of the immunizations.) Meningococcal vaccine proof is required for all incoming undergraduate students. A PPD skin test in the past six months is required for students entering the university from certain countries. This list of countries may be found on our website. We suggest all students also have Tetanus Diphtheria immunization within the past five years, Hepatitis A vaccine series, Hepatitis B vaccine series and Varicella vaccine. Medical History Forms (<http://shs.wustl.edu>) are available online. Failure to complete the required forms will delay registration and will prevent entrance into housing assignment. Please visit our website for complete information about requirements and deadlines (<http://shs.wustl.edu>).

Mental Health Services staff members work with students to resolve personal and interpersonal difficulties, including conflicts with or worry about friends or family, concerns about eating or drinking patterns, and feelings of anxiety and depression. Although some concerns are more frequent than others, students' experiences are as varied as the students themselves. Staff members help each person figure out their own situation. Services include individual, group and couples counseling; crisis counseling; psychiatric consultation; and referral for off-campus

counseling. Call 314-935-6666 or visit our website to schedule an appointment (<http://shs.wustl.edu>).

Health Promotion Services staff members provide information and resources on issues of interest to Washington University students including alcohol and other drugs, weight and body image, sexual health, sleep and stress; customize professional health education programs for groups; and work with groups of students dedicated to educating their peers about healthy decision making. Call 314-935-7139 for more information.

Important Information About Health Insurance, Danforth Campus

Washington University has a student health fee designed to improve the health and wellness of the entire Washington University community. This fee supports health and wellness services and programs on campus. In addition, all full-time, degree-seeking Washington University students are automatically enrolled in the Student Health Insurance Plan upon completion of registration. Students may opt out of this coverage if there is proof of existing comprehensive insurance coverage. Information concerning opting out of the student health insurance plan (<http://shs.wustl.edu>) can be found online after June 1 of each year. Habif does provide billing services to many of the major insurance companies in the United States. Specific fees and co-pays apply to students using Medical Services and Mental Health Services; these fees may be billable to your insurance plan. More information is available on the Habif Health and Wellness Center website (<http://shs.wustl.edu>).

Student Health Services, Medical Campus

For information about student health services on the Medical Campus, please visit the Student Health Services page (<http://bulletin.wustl.edu/medicine/resources/student-health>) of the medical school *Bulletin*.

Campus Security

The Washington University campus is among the most attractive in the nation and enjoys a safe, relaxed atmosphere. Your personal safety and the security of your property while on campus is a shared responsibility. Washington University has made safety and security a priority through our commitment to a full-time professional police department, use of closed circuit television, card access, good lighting, shuttle services, emergency telephones, and ongoing educational safety awareness programs. The vast majority of crimes that occur on college campuses are crimes of opportunity, which can be prevented.

The best protection against crime is an informed, alert campus community. Washington University has developed several programs to help make your experience here a safe and secure one. An extensive network of emergency telephones, including

more than 200 "blue light" telephones, is connected directly to the University Police Department and can alert the police to your exact location. In addition to the regular shuttle service, an evening walking escort service or mobile Campus Circulator is available on the Danforth Campus.

The Campus2Home shuttle will provide a safe ride home for those living in four designated areas off campus — Skinker-DeBaliviere, Loop South, north of The Loop and just south of the campus — from 6:00 p.m. to 4:00 a.m. seven days a week. The shuttle leaves from the Mallinckrodt Center and takes passengers directly to the front doors of their buildings. Shuttle drivers then will wait and watch to make sure passengers get into their buildings safely. Community members can track the shuttle using the WUSTL Mobile App. The app can be downloaded free of charge from the iOS App Store or the Google Play store.

The University Police Department is a full-service organization staffed by certified police officers who patrol the campus 24 hours a day throughout the entire year. The Police Department offers a variety of crime prevention programs including a high-security bicycle lock program, free personal-safety whistles, computer security tags, personal safety classes for women and men, property inventory services and security surveys. Community members are encouraged to download the personal safety app SafeTrek which allows users to call for help during emergencies. The SafeTrek app (<https://www.safetrekapp.com/affiliate/WUSTL>) can be downloaded online. For more information on these programs, check out the Washington University Police Department website (<http://police.wustl.edu>).

In compliance with the Campus Crime Awareness and Security Act of 1990, Washington University publishes online an annual report (<http://police.wustl.edu/clerylogsandreports/Pages/default.aspx>), *Safety & Security: Guide for Students, Faculty, and Staff, Annual Campus Security and Fire Safety Reports*, which is available to all current and prospective students on the Danforth Campus and university employees on the Danforth, North and West campuses. To request a hard copy, contact the Washington University Police Department, CB 1038, One Brookings Drive, St. Louis, MO 63130-4899, 314-935-9011.

For information regarding protective services at the School of Medicine, please visit the Security page (<https://facilities.med.wustl.edu/security>) of the Washington University Operations & Facilities Management Department.

University Policies

Washington University has various policies and procedures that govern our faculty, staff and students. Highlighted below are several key policies of the university. Web links to key policies and procedures are available on the Office of the University Registrar website (<http://registrar.wustl.edu>) and on the university's Compliance and Policies page (<http://wustl.edu/policies>). Please note that the policies identified on these

websites and in this *Bulletin* do not represent an entire repository of university policies, as schools, offices and departments may implement policies that are not listed. In addition, policies may be amended throughout the year.

Nondiscrimination Statement

Washington University encourages and gives full consideration to all applicants for admission, financial aid and employment. The university does not discriminate in access to, or treatment or employment in, its programs and activities on the basis of race, color, age, religion, sex, sexual orientation, gender identity or expression, national origin, veteran status, disability or genetic information.

Policy on Discrimination and Harassment

Washington University is committed to having a positive learning and working environment for its students, faculty and staff. University policy prohibits discrimination on the basis of race, color, age, religion, sex, sexual orientation, gender identity or expression, national origin, veteran status, disability or genetic information. Harassment based on any of these classifications is a form of discrimination and violates university policy and will not be tolerated. In some circumstances such discriminatory harassment may also violate federal, state or local law. A copy of the Policy on Discrimination and Harassment (<http://hr.wustl.edu/policies/Pages/DiscriminationAndHarassment.aspx>) is available on the Human Resources website.

Sexual Harassment

Sexual harassment is a form of discrimination that violates university policy and will not be tolerated. It is also illegal under state and federal law. Title IX of the Education Amendments of 1972 prohibits discrimination based on sex (including sexual harassment and sexual violence) in the university's educational programs and activities. Title IX also prohibits retaliation for asserting claims of sex discrimination. The university has designated the Title IX Coordinator identified below to coordinate its compliance with and response to inquiries concerning Title IX.

For more information or to report a violation under the Policy on Discrimination and Harassment, please contact:

Discrimination and Harassment Response Coordinators

Apryle Cotton, Asst. Vice Chancellor for Human Resources
Section 504 Coordinator
Phone: 314-362-6774
Email (apryle.cotton@wustl.edu)

Leanne Stewart, Employee Relations Manager
Phone: 314-362-8278
Email (leannerstewart@wustl.edu)

Title IX Coordinator

Jessica Kennedy, Director of Title IX Office

Title IX Coordinator
Phone: 314-935-3118
Email (jwkennedy@wustl.edu)

You may also submit inquiries or a complaint regarding civil rights to the United States Department of Education's Office of Civil Rights at 400 Maryland Avenue, SW, Washington, DC 20202-1100 or by visiting the U.S. Department of Education website (<http://ed.gov>) or calling 800-421-3481.

Student Health

Drug and Alcohol Policy

Washington University is committed to maintaining a safe and healthful environment for members of the university community by promoting a drug-free environment as well as one free of the abuse of alcohol. Violations of the Washington University Drug and Alcohol Policy (<http://hr.wustl.edu/policies/Pages/DrugandAlcoholPolicy.aspx>) or Alcohol Service Policy (<http://pages.wustl.edu/prograds/alcohol-service-policy>) will be handled according to existing policies and procedures concerning the conduct of faculty, staff and students. This policy is adopted in accordance with the Drug-Free Workplace Act and the Drug-Free Schools and Communities Act.

Tobacco-Free Policy

Washington University is committed to providing a healthy, comfortable and productive work and learning environment for all students, faculty and staff. Research shows that tobacco use in general, including smoking and breathing secondhand smoke, constitutes a significant health hazard. The university strictly prohibits all smoking and other uses of tobacco products within all university buildings and on university property, at all times. A copy of our complete tobacco-free policy (<http://hr.wustl.edu/policies/Pages/tobaccofreepolicy.aspx>) is available on the Human Resources website.

Medical Examinations

Entering students must provide medical information to the Habif Health and Wellness Center. This will include completion of a health history and a record of all current immunizations. The university strongly recommends appropriate vaccination for meningococcal disease.

If students fail to comply with these requirements prior to registration, they will be required to obtain vaccinations for measles, mumps and rubella at the Habif Health and Wellness Center, if there is no evidence of immunity. They will be assessed the cost of the vaccinations. Students will be unable to complete registration for classes until all health requirements have been satisfied.

If students are unimmunized, they may be barred from classes and from all university facilities, including housing units, if in the judgment of the university their continued presence would pose a health risk to themselves or to the university community.

Medical and immunization information is to be given via the Habif Health and Wellness Center (<http://shs.wustl.edu>) website. All students who have completed the registration process should access the website and create a student profile by using their WUSTL key. Creating a student profile enables a student to securely access the medical history form. Fill out the form and follow the instructions for transmitting it to the Habif Health and Wellness Center. Student information is treated securely and confidentially.

Student Conduct

The Student Conduct Code sets forth community standards and expectations for Washington University students. These community standards and expectations are intended to foster an environment conducive to learning and inquiry. Freedom of thought and expression is essential to the university's academic mission.

Disciplinary proceedings are meant to be informal, fair and expeditious. Charges of non-serious misconduct are generally heard by the student conduct officer. With limited exceptions, serious or repeated allegations are heard by the campuswide Student Conduct Board or the University Sexual Assault Investigation Board where applicable.

Complaints against students that include allegations of sexual assault or certain complaints that include allegations of sexual harassment in violation of the Student Conduct Code are governed by the procedures found in the University Sexual Assault Investigation Board Policy (<https://wustl.edu/about/compliance-policies/governance/usaib-procedures-complaints-sexual-assault-filed-students>), which is available online or in hard copy from the Title IX coordinator or the director of Student Conduct and Community Standards.

Students may be accountable to both governmental authorities and to the university for acts that constitute violations of law and the Student Conduct Code.

For a complete copy of the Student Conduct Code (<https://wustl.edu/about/compliance-policies/academic-policies/university-student-judicial-code>), visit the university website.

Undergraduate Student Academic Integrity Policy

Effective learning, teaching and research all depend upon the ability of members of the academic community to trust one another and to trust the integrity of work that is submitted for academic credit or conducted in the wider arena of scholarly research. Such an atmosphere of mutual trust fosters the free exchange of ideas and enables all members of the community to achieve their highest potential.

In all academic work, the ideas and contributions of others must be appropriately acknowledged, and work that is presented as original must be, in fact, original. Faculty, students and

administrative staff all share the responsibility of ensuring the honesty and fairness of the intellectual environment at Washington University.

Scope and Purpose

This statement on academic integrity applies to all undergraduate students at Washington University. Graduate students are governed by policies in each graduate school or division. All students are expected to adhere to the highest standards of behavior. The purpose of the statement is twofold:

- To clarify the university's expectations with regard to undergraduate students' academic behavior, and
- To provide specific examples of dishonest conduct. The examples are only illustrative, *not* exhaustive.

Violations of This Policy Include, but Are Not Limited To:

1. Plagiarism

Plagiarism consists of taking someone else's ideas, words or other types of work product and presenting them as one's own. To avoid plagiarism, students are expected to be attentive to proper methods of documentation and acknowledgment. To avoid even the suspicion of plagiarism, a student must always:

- Enclose every quotation in quotation marks and acknowledge its source.
- Cite the source of every summary, paraphrase, abstraction or adaptation of material originally prepared by another person and any factual data that is not considered common knowledge. Include the name of author, title of work, publication information and page reference.
- Acknowledge material obtained from lectures, interviews or other oral communication by citing the source (name of the speaker, the occasion, the place and the date).
- Cite material from the internet as if it were from a traditionally published source. Follow the citation style or requirements of the instructor for whom the work is produced.

2. Cheating on an Examination

A student must not receive or provide any unauthorized assistance on an examination. During an examination a student may use only materials authorized by the faculty.

3. Copying or Collaborating on Assignments without Permission

When a student submits work with their name on it, this is a written statement that credit for the work belongs to that student alone. If the work was a product of collaboration, each student is expected to clearly acknowledge in writing all persons who contributed to its completion.

Unless the instructor explicitly states otherwise, it is dishonest to collaborate with others when completing any

assignment or test, performing laboratory experiments, writing and/or documenting computer programs, writing papers or reports, and completing problem sets.

If the instructor allows group work in some circumstances but not others, it is the student's responsibility to understand the degree of acceptable collaboration for each assignment, and to ask for clarification if necessary.

To avoid cheating or unauthorized collaboration, a student should never:

- Use, copy or paraphrase the results of another person's work and represent that work as one's own, regardless of the circumstances.
- Refer to, study from or copy archival files (e.g., old tests, homework, solutions manuals or backfiles) that were not approved by the instructor.
- Copy another's work or permit another student to copy one's work.
- Submit work as a collaborative effort if they did not contribute a fair share of the effort.

4. Fabrication or Falsification of Data or Records

It is dishonest to fabricate or falsify data in laboratory experiments, research papers or reports or in any other circumstances; to fabricate source material in a bibliography or "works cited" list; or to provide false information on a résumé or other document in connection with academic efforts. It is also dishonest to take data developed by someone else and present them as one's own.

Examples of falsification include:

- Altering information on any exam, problem set or class assignment being submitted for a re-grade.
- Altering, omitting or inventing laboratory data to submit as one's own findings. This includes copying laboratory data from another student to present as one's own; modifying data in a write-up; and providing data to another student to submit as one's own.

5. Other Forms of Deceit, Dishonesty or Inappropriate Conduct

Under no circumstances is it acceptable for a student to:

- Submit the same work, or essentially the same work, for more than one course without explicitly obtaining permission from all instructors. A student must disclose when a paper or project builds on work completed earlier in their academic career.
- Request an academic benefit based on false information or deception. This includes requesting an extension of time, a better grade or a recommendation from an instructor.
- Make any changes (including adding material or erasing material) on any test paper, problem set or class assignment being submitted for a re-grade.
- Willfully damage the efforts or work of other students.

- Steal, deface or damage academic facilities or materials.
- Collaborate with other students planning or engaging in any form of academic misconduct.
- Submit any academic work under someone else's name other than one's own. This includes but is not limited to sitting for another person's exam; both parties will be held responsible.
- Engage in any other form of academic misconduct not covered here.

This list is not intended to be exhaustive. To seek clarification, students should ask the professor or the assistant in instruction for guidance.

Reporting Misconduct

Faculty Responsibility

Faculty and instructors are strongly encouraged to report incidents of student academic misconduct to the academic integrity officer in their school or college in a timely manner so that the incident may be handled fairly and consistently across schools and departments. Assistants in instruction are expected to report instances of student misconduct to their supervising instructors. Faculty members are expected to respond to student concerns about academic dishonesty in their courses.

Student Responsibility

If a student observes others violating this policy, the student is strongly encouraged to report the misconduct to the instructor, to seek advice from the academic integrity officer of the school or college that offers the course in question, or to address the student(s) directly.

Exam Proctor Responsibility

Exam proctors are expected to report incidents of suspected student misconduct to the course instructor and/or the Disability Resource Center, if applicable.

Procedure

Jurisdiction

This policy covers all undergraduate students, regardless of their college of enrollment. Cases will be heard by school-specific committees according to the school in which the class is listed, not the school in which the student is enrolled. All violations and sanctions will be reported to the student's college of enrollment.

Administrative Procedures

Individual undergraduate colleges and schools may design specific procedures to resolve allegations of academic misconduct by students in courses offered by that school, so long as the procedures are consistent with this policy and with the Student Conduct Code.

Student Rights and Responsibilities in a Hearing

A student accused of an academic integrity violation, whether by a professor, assistant in instruction, academic integrity officer or student, is entitled to:

- Review the written evidence in support of the charge.
- Ask any questions.
- Offer an explanation as to what occurred.
- Present any material that would cast doubt on the correctness of the charge.
- Determination of the validity of the charge without reference to any past record of misconduct.

When responding to a charge of academic misconduct, a student may:

- Deny the charges and request a hearing in front of the appropriate academic integrity officer or committee.
- Admit the charges and request a hearing to determine sanction(s).
- Admit the charges and accept the imposition of sanctions without a hearing.
- Request a leave of absence from the university. The academic integrity matter must be resolved prior to re-enrollment.
- Request to withdraw permanently from the university with a transcript notation that there is an unresolved academic integrity matter pending.

A student has the following responsibilities in resolving the charge of academic misconduct:

- Admit or deny the charge. This will determine the course of action to be pursued.
- Provide truthful information regarding the charges. It is a Student Conduct Code violation to provide false information to the university or anyone acting on its behalf.

Sanctions

If Found *Not* in Violation of the Academic Integrity Policy

If the charges of academic misconduct are not proven, no record of the allegation will appear on the transcript.

If Found in Violation of the Academic Integrity Policy

If, after a hearing, a student is found to have acted dishonestly, or if a student has admitted to the charges prior to a hearing, the school's academic integrity officer or committee may impose sanctions, including but not limited to the following:

- Issue a formal written reprimand.
- Impose educational sanctions, such as completing a workshop on plagiarism or academic ethics.
- Recommend to the instructor that the student fail the assignment. (A grade is ultimately the prerogative of the instructor.)
- Recommend to the instructor that the student fail the course.
- Recommend to the instructor that the student receive a course grade penalty less severe than failure of the course.
- Place the student on disciplinary probation for a specified period of time or until defined conditions are met. The probation will be noted on the student's transcript and internal record while it is in force.
- In cases serious enough to warrant suspension or expulsion from the university, refer the matter to the Student Conduct Board for consideration.

Additional educational sanctions may be imposed. This list is not intended to be exhaustive.

Withdrawing from the course will not prevent the academic integrity officer or hearing panel from adjudicating the case, imposing sanctions or recommending grade penalties, including a failing grade in the course.

A copy of the sanction letter will be placed in the student's academic file.

Appeals

If a student believes the academic integrity officer or the committee did not conduct a fair hearing, or if a student believes the sanction imposed for misconduct is excessive, they may appeal to the Student Conduct Board within 14 days of the original decision. Appeals are governed by Section VII C of the Student Conduct Code.

Records

Administrative Record-Keeping Responsibilities

It is the responsibility of the academic integrity officer in each school to keep accurate, confidential records concerning academic integrity violations. When a student has been found to have acted dishonestly, a letter summarizing the allegation, the outcome and the sanction shall be placed in the student's official file in the office of the school or college in which the student is enrolled.

Additionally, each school's academic integrity officer shall make a report of the outcome of every formal accusation of student academic misconduct to the director of Student Conduct and Community Standards, who shall maintain a record of each incident.

Multiple Offenses

When a student is formally accused of academic misconduct and a hearing is to be held by an academic integrity officer, a committee, or the Office of Student Conduct and Community Standards, the person in charge of administering the hearing shall query the Office of Student Conduct and Community Standards about the student(s) accused of misconduct. The director shall provide any information in the records concerning that student to the integrity officer. Such information will be used in determining sanctions *only* if the student is found to have acted dishonestly in the present case. Evidence of past misconduct may not be used to resolve the issue of whether a student has acted dishonestly in a subsequent case.

Reports to Faculty and Student Body

School and college academic integrity officers are encouraged to make periodic (at least annual) reports to the students and faculty of their school concerning accusations of academic misconduct and the outcomes, without disclosing specific information that would allow identification of the student(s) involved.

Graduate Student Academic Integrity Policies

For graduate student academic integrity policies, please refer to each individual graduate school.

Statement of Intent to Graduate

Students are required to file an Intent to Graduate at WebSTAC (<https://acadinfo.wustl.edu>) prior to the semester in which they intend to graduate. Additional information is available in the dean's offices of each school and in the Office of the University Registrar (<http://registrar.wustl.edu>).

Student Academic Records and Transcripts

The Family Educational Rights and Privacy Act of 1974 (FERPA) — Title 20 of the United States Code, Section 1232g, as amended — provides current and former students of the university with specific rights of access to and control over their student record information. In compliance with the statute, appropriate federal regulations and guidelines recommended by the American Association of Collegiate Registrars and Admissions Officers, the university has adopted procedures that implement these rights.

A copy of the university policies regarding educational records and the release of student record information is available from the Office of the University Registrar (<http://registrar.wustl.edu>) and the university website (<https://wustl.edu>).

Transcript requests for Danforth Campus students may be submitted to the Office of the University Registrar through WebSTAC. The School of Medicine registrar ([http://](http://registrar.med.wustl.edu/services/transcripts-and-certification)

registrar.med.wustl.edu/services/transcripts-and-certification) accepts requests for transcripts and certification records for students and alumni of: Audiology and Communication Sciences, Clinical Investigation, Genetic Epidemiology, Health Administration, Nurse Anesthesia, Occupational Therapy, Pediatric Nurse Practitioner, Physical Therapy, Psychiatric Epidemiology, School of Dentistry and School of Medicine. Instructions and additional information are available on the University Registrar website (<http://registrar.wustl.edu>).

University Affiliations

Washington University is accredited by the Higher Learning Commission (<https://www.hlcommission.org>) (800-621-7440). Washington University is a member of the Association of American Universities, the American Council on Education, the College Board, and the Independent Colleges and Universities of Missouri.

The College of Arts & Sciences is a member of the American Association of Collegiate Registrars and Admissions Officers (AACRAO) and the International Center for Academic Integrity (ICAI).

The College of Architecture was one of the eight founding members of the Association of Collegiate Schools of Architecture (ACSA) in 1912.

The Graduate School is a founding member of both the Association of Graduate Schools and the Council of Graduate Schools.

The Graduate School of Architecture & Urban Design's Master of Architecture degree is accredited by the National Architectural Accreditation Board (NAAB).

The Sam Fox School of Visual Arts & Design (Art) is a founding member of, and is accredited by, the National Association of Schools of Art and Design (NASAD).

The Olin Business School is a charter member of the Association to Advance Collegiate Schools of Business International (AACSB).

In the School of Engineering & Applied Science, many of the professional degrees are accredited by the Engineering Accreditation Commission of ABET (<http://abet.org>).

University College is a member of the University Professional and Continuing Education Association, the North American Association of Summer Sessions, the Association of University Summer Sessions and the Center for Academic Integrity. Business-related programs in University College are not accredited by the Association to Advance Collegiate Schools of Business (AACSB International).

The School of Law is accredited by the American Bar Association. The School of Law is a member of the Association of American Law Schools, the American Society of Comparative Law, the Clinical Legal Education Association, the Southeastern

Association of Law Schools, the Central Law Schools Association, the Mid-America Law Library Consortium, the American Association of Law Libraries, and the American Society of International Law.

The School of Medicine is a member of the Liaison Committee on Medical Education.

The Brown School at Washington University is accredited by the Council on Social Work Education and the Council on Education for Public Health.

The University Libraries are a member of the Association of Research Libraries.

The Mildred Lane Kemper Art Museum is nationally accredited by the American Alliance of Museums.

School of Engineering & Applied Science

The School of Engineering & Applied Science offers programs of instruction and research leading to specified master's and doctoral degrees.

Both full-time and part-time students may pursue most of the graduate programs offered by Engineering. A few graduate programs are designed primarily for full-time students. However, numerous locally employed engineers, scientists and technical managers have earned master's degrees through part-time study. Many evening graduate courses are offered, and many other graduate courses are taught during the late afternoon. Students who are employed full-time and are interested in investigating the possibility of doctoral graduate work should consult directly with the director of the particular department or program in which they are interested.

Contact Information

School of Engineering & Applied Science
Lopata Hall, Suite 204
Washington University in St. Louis
CB 1220
One Brookings Drive
St. Louis, MO 63130-4899
314-935-7974 (Admissions)
314-935-5830 (Graduate Student Services)

Email: gradadmissions@seas.wustl.edu

Website: <http://engineering.wustl.edu/>

Doctoral Degrees

Doctor of Philosophy

The Doctor of Philosophy (PhD) degree is not only an exploration of the knowledge in a given discipline but also an original contribution to it. To the extent that doctoral education has been successful, the student's relationship to learning is significantly changed. Having made a discovery, developed an insight, tested a theory, or designed an application, the PhD recipient is no longer a student but a colleague of the faculty. It is for this reason that the PhD is the highest degree offered by a university.

The core mission of PhD programs at research universities is to educate the future faculty of other research universities and institutions of higher education. Graduates of Washington University participate in research and teaching; they also make valuable contributions to society by applying the analytical and creative skills required for scholarship to careers in business,

government, and nonprofit sectors. The Graduate School therefore works with other university offices to ensure that students have the opportunity to develop these transferable skills.

Among the critical components the university provides for these purposes are a small and select graduate student body, faculty members dedicated to scholarly work, and the physical facilities needed for research. In these regards Washington University compares favorably to the finest graduate institutions in the world. But the key ingredients of PhD completion must be provided by the student: a love of learning and a desire to increase the sum of human knowledge. Motivation and perseverance are prerequisites for success in PhD programs.

Doctor of Science

The Doctor of Science (DSc) degree is conferred in recognition of the candidate's abilities and attainments in some field of engineering or applied science. The DSc is a doctorate in science equivalent to a PhD doctoral degree. The departments of Electrical & Systems Engineering and Mechanical Engineering & Materials Science offer both the PhD and DSc doctoral options for graduate students. For information about the differences between the PhD and DSc degrees, please refer to the DSc and PhD Comparison (PDF) (<https://mems.wustl.edu/graduate/programs/Documents/DoctoralComparisonSection.pdf>).

General Requirements

Candidates for doctoral degrees at Washington University must complete all courses required by their department, maintain satisfactory academic progress, pass certain examinations, fulfill residence and teaching requirements (if applicable), write, defend, and submit a dissertation, and file an Intent to Graduate form on WebSTAC (<https://acadinfo.wustl.edu>).

Engineering-based doctoral degrees require a minimum of 72 units. The doctoral program requires 36-48 units of course work and 24-36 units of research. The specific distribution decisions are made by the individual programs and departments.

The doctorate can be awarded only to those students whose knowledge of their field of specialization meets contemporary standards. Course work completed more than seven years prior to the date the degree is awarded generally cannot be accepted as satisfying degree requirements. No courses will be accepted toward degree requirements if the course exceeds the 10-year maximum time period unless they have formal approval of the Engineering Graduate Board. Additionally, all milestone requirements for the degree must be completed within seven years from the time the student is admitted to a graduate program.

The doctoral degree has a residency requirement of one year. To satisfy the requirement, the student must devote full time for two consecutive semesters to academically relevant activities on the Washington University campus. A limited amount of outside

employment may be permitted, but only with the approval of the department or program chairman and/or the dean. Candidates for the Doctor of Philosophy degree are required to follow the guidelines of the Graduate School. Please refer to the Graduate School website (<http://graduateschool.wustl.edu>) for policies and guidelines for the Doctor of Philosophy degree. Candidates for the Doctor of Science degree are required to follow the guidelines of the School of Engineering & Applied Science (SEAS). Please refer to the DSc and PhD Comparison (PDF) (<https://mems.wustl.edu/graduate/programs/Documents/DoctoralComparisonSection.pdf>) for more information about the DSc requirements.

Adviser & Doctoral Committee

Once admitted to graduate standing, each doctoral student will have an adviser appointed by the chair or director of the designated area of specialization. It is the responsibility of the adviser to help the student plan a graduate program.

Each department within the School of Engineering & Applied Science has its own policy related to selection of a doctoral committee; therefore, students should consult with their faculty adviser regarding appointment of their doctoral committee.

Doctoral Qualifying Examination

To be admitted to a candidacy for the doctoral degree, a student must pass a comprehensive qualifying examination that may consist of both written and oral portions. The examination is administered by the student's department or program, and students should consult their adviser for information concerning the scope of the examination and the dates on which it is given. The examining panel will consist of faculty members approved by the department chair or program director.

Doctoral Dissertation

Doctoral candidates must submit a satisfactory dissertation which involves independent, creative work in an area of specialization, and which demonstrates an ability for critical and constructive thinking. It must constitute a definite contribution to knowledge in some field of engineering or applied science. The research which is the subject of the dissertation must have been performed under the supervision of a member of the faculty of the School of Engineering & Applied Science. The candidate must defend the dissertation during a final oral examination by an examining committee to be nominated by the adviser and approved by the appropriate dean.

Doctor of Philosophy candidates should refer to the Doctoral Dissertation Guide (http://graduateschool.wustl.edu/sites/graduateschool.wustl.edu/files/Doctoral%20Dissertation%20Guide%202018_Links.pdf) found on the Graduate School website for specific information on preparing their dissertation for submission. Doctor of Science students should prepare their dissertation according to the DSc & Master's Thesis Format Guidelines (<https://engineering.wustl.edu/current-students/>

[student-services/Pages/forms.aspx#thesis-submission](https://engineering.wustl.edu/current-students/)) found on the Engineering website.

Each candidate for the doctoral degree must electronically submit a final approved version of their dissertation. The dissertation should include an abstract embodying the principal findings of the research and approved by the doctoral committee as ready for publication. Such abstract will be published in Dissertation Abstracts, which announces the availability of the dissertation for distribution.

Master's Degrees

Master of Engineering versus Master of Science Degrees

Master of Engineering (MEng) degrees are typically viewed as terminal degrees allowing maximum flexibility in course selection. Master of Science (MS) degrees are more structured in terms of required course work, and students with undergraduate degrees specifically in engineering are often better prepared to enter these master's programs. Graduates from Master of Science programs are better prepared to move forward to doctoral programs, as they often become more involved in research experience. However, Master of Science programs also include course-only options for those not interested in doing research.

There are different ways to earn a master's degree at Washington University:

- There are a number of Engineering disciplines that admit students to pursue a terminal master's degree. In some programs both the course option and thesis option are available.
- Undergraduate students at Washington University may apply for the Bachelor's/Master's program in Engineering, in which graduation with a BS or AB is followed by one year of graduate study leading to the MEng or MS degree. This option is described in the Combined Majors and/or Multiple Degrees (<http://bulletin.wustl.edu/undergrad/engineering/#combinedmajors>) section of the *Undergraduate Bulletin*.
- Students who have not previously earned a master's degree in the same field as their PhD may earn the MS on the way to their PhD. This option is available in some disciplines but not in all of them.
- Students who have not previously earned a master's degree in the same field as their PhD may be awarded an MS for work done in a PhD program that they are leaving without completing. This option is available in some disciplines but not in all of them.

General Requirements

Candidates for master's degrees should note that in most MS programs both the thesis option and the course option are available. The course option may be of particular interest to part-

time students who, because of their employment, might find it more convenient than the thesis requirement. All candidates for the master's degrees should consult with their adviser to determine the option they will follow.

All requirements for master's degrees must be completed within six years from the time the student is admitted to graduate standing. A maximum of six units of graduate credit obtained at institutions other than Washington University may be applied toward the master's degree awarded by Engineering. Transfer credit must be recommended and approved by the department chair or program director and adviser, as well as by the Engineering registrar. No courses carrying grades lower than B can be accepted for transfer credit.

For the thesis option, a minimum of 24 units of course work and a minimum of 6 units of research are required. The student must also write a satisfactory thesis prepared under the supervision of a member of the Engineering faculty. Candidates for master's degrees under the course option must submit a minimum of 30 units of approved graduate course credit. A department may have additional requirements beyond the above stated minimum requirement. Students should consult with their adviser as several master's degrees require more than 30 graduate units.

Multiple Master's Degrees

To earn more than one master's degree from Engineering, the student's final program of course work for each such master's degree must include a minimum of 15 units of preapproved courses not included as part of the final program of course work for any other master's degree awarded by Engineering.

Master's Thesis

A candidate for the degree Master of Science (thesis option) should prepare their thesis according to the Master's Thesis Format Guidelines (<http://engineering.wustl.edu/current-students/student-services/Pages/forms.aspx>) found on the Engineering website.

The candidate's department chair or program director will appoint a thesis committee of three faculty members, with the student's adviser as chair, who will read the thesis and judge its acceptability. At some point, as per published deadlines, the candidate will then deliver a draft copy of the thesis to the Engineering Student Services Office for format approval. Three copies of the final thesis accepted by the committee and approved for format must be delivered to the Engineering Student Services Office no later than the deadline stated in the online academic calendar. In addition, prior to submission of the final hard copies, the student must submit the document electronically to Washington University Open Scholarship (http://openscholarship.wustl.edu/cgi/ir_submit.cgi?context=eng_etds).

Master's Final Examinations

The final examination for the Master of Science candidates under the thesis option consists of an oral examination conducted by the thesis committee and any additional faculty members that the department or program chairman may wish to designate. At this examination the candidate will present and defend the thesis.

Candidates for the Master of Science under the course option may be required to pass a final examination. The form of this examination is determined by the faculty of the area of specialization, and students should consult their advisers, department chairs, or program directors for details concerning this examination.

Fields of Study

- Biomedical Engineering (p. 16)
- Computer Science & Engineering (p. 26)
- Electrical & Systems Engineering (p. 40)
- Energy, Environmental & Chemical Engineering (p. 54)
- Imaging Science (Interdisciplinary PhD) (p. 61)
- Materials Science & Engineering (p. 67)
- Mechanical Engineering & Materials Science (p. 73)

For additional graduate programs, please visit the Henry Edwin Sever Institute (p. 85) section of this *Bulletin*.

Biomedical Engineering

Biomedical engineering (BME) seeks to advance and integrate life science knowledge with engineering methods and innovations that contribute to improvements in human health and well-being. Our vision is that lasting knowledge of biomedical systems and paradigm-shifting engineering technology will arise from integrating engineering concepts and basic science knowledge across molecular to whole-body levels. We believe that those taught to work across multiple disciplines, and to integrate modeling and experimental systems approaches, will be uniquely positioned to advance and generate new disciplines in biomedical engineering.

With this vision in mind, we are committed to educating the next generation of biomedical engineers. We have leveraged our interdisciplinary strengths in engineering, and clinical and life sciences, to build a biomedical engineering department around research programs of excellence and translational potential: Biomedical & Biological Imaging; Cancer Technologies; Cardiovascular Engineering; Molecular & Cellular Systems Engineering; Neural Engineering; Orthopedic Engineering; and Regenerative Engineering in Medicine. These areas provide exciting opportunities for students with a variety of backgrounds and interests.

Students seeking the **Master of Science (MS) in Biomedical Engineering** will need to complete 30 course credits which

includes a core curriculum. MS students pursuing the thesis option perform research on a topic approved by the research mentor. Results of the study are published in a thesis that is defended in front of a committee of faculty members prior to graduation. The results should be of quality high enough to be published as a paper in a peer-reviewed journal. A total of 30 credits can be completed in 2-4 semesters.

Students seeking the **Master of Engineering (MEng) in Biomedical Innovation** will complete an immersive 12-month medical technology entrepreneurial experience culminating in their own intellectual property intended to be spun out into commercial endeavors following graduation. A total of 30 credits of course work is required.

Students seeking the **PhD in Biomedical Engineering** may choose to study in one of seven multidisciplinary research programs that represent frontiers in biomedical engineering. Our core faculty work collaboratively with more than 90 affiliated faculty to offer students the opportunity to learn in a diverse and rich spectrum of BME research areas. Students graduating with the PhD in Biomedical Engineering are prepared to pursue paths in research and development in academic and industry settings, and are well-prepared to contribute to teaching and research translation. The **MD/PhD in Biomedical Engineering**, given jointly with the top-ranked School of Medicine, gives students in-depth training in modern biomedical research and clinical medicine. The typical MD/PhD career combines patient care and biomedical research but leans toward research.

Email: bme@seas.wustl.edu
Website: <https://bme.wustl.edu/graduate>

Faculty

Chair

Lori A. Setton (<https://engineering.wustl.edu/Profiles/Pages/Lori-Setton.aspx>)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomaterials for local drug delivery; tissue regenerations specific to the knee joints and spine

Endowed Professors

Rohit V. Pappu (<https://engineering.wustl.edu/Profiles/Pages/Rohit-Pappu.aspx>)
Edwin H. Murty Professor of Engineering
PhD, Tufts University
Macromolecular self assembly and function; computational biophysics

Yoram Rudy (<https://engineering.wustl.edu/Profiles/Pages/Yoram-Rudy.aspx>)
Fred Saigh Distinguished Professor of Engineering
PhD, Case Western Reserve University
Cardiac electrophysiology; modeling of the cardiac system

Professors

Mark Anastasio (<https://engineering.wustl.edu/Profiles/Pages/Mark-Anastasio.aspx>)
PhD, University of Chicago
Imaging sciences; phase-contrast; x-ray imaging

Jianmin Cui (<https://engineering.wustl.edu/Profiles/Pages/Jianmin-Cui.aspx>)
PhD, State University of New York–Stony Brook
Ion channels; channel structure-function relationship; biophysics

Daniel Moran (<https://engineering.wustl.edu/Profiles/Pages/Daniel-Moran.aspx>)
PhD, Arizona State University
Motor control; neural engineering; neuroprosthetics; movement biomechanics

Quing Zhu (<https://engineering.wustl.edu/Profiles/Pages/Quing-Zhu.aspx>)
PhD, University of Pennsylvania
Biophotonics and multimodality ultrasound and optical imaging

Associate Professors

Dennis L. Barbour (<https://engineering.wustl.edu/Profiles/Pages/Dennis-Barbour.aspx>)
MD, PhD, Johns Hopkins University
Auditory physiology; sensory cortex neurocircuitry; novel perceptual diagnostics and therapeutics

Princess Imoukhuede (<https://engineering.wustl.edu/Profiles/Pages/Princess-Imoukhuede.aspx>)
PhD, California Institute of Technology
Ligand-receptor signal transduction; angiogenesis; computational systems bioengineering

Vitaly Klyachko (<https://engineering.wustl.edu/Profiles/Pages/Vitaly-Klyachko.aspx>)
PhD, University of Wisconsin-Madison
Synaptic function and plasticity; neural circuits; information analysis; neurological disorders

Baranidharan Raman (<https://engineering.wustl.edu/Profiles/Pages/Barani-Raman.aspx>)
PhD, Texas A&M University
Computational and systems neuroscience; neuromorphic engineering; pattern recognition; sensor-based machine olfaction

Jin-Yu Shao (<https://engineering.wustl.edu/Profiles/Pages/Jin-Yu-Shao.aspx>)
PhD, Duke University
Cell mechanics; receptor and ligand interactions; molecular biomechanics

Kurt A. Thoroughman (<https://engineering.wustl.edu/Profiles/Pages/Kurt-Thoroughman.aspx>)
PhD, Johns Hopkins University
Human motor control and motor learning; neural computation

Assistant Professors

Hong Chen (<https://engineering.wustl.edu/Profiles/Pages/Hong-Chen.aspx>)
PhD, University of Washington
Physical acoustics; therapeutic ultrasound and ultrasound imaging

Nate Huebsch (<https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=114>)
PhD, Harvard University
Cell-material Interactions, iPSC-based tissue modeling to study cardiac development and disease

Abhinav Kumar Jha (<https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=125>)
PhD, University of Arizona
Development of computational-imaging solutions for diagnosing and treating diseases

Kristen Naegle (<https://engineering.wustl.edu/Profiles/Pages/Kristen-Naegle.aspx>)
PhD, Massachusetts Institute of Technology
Computational systems biology with emphasis on cellular networks involved in cancer and diabetes

Jai S. Rudra (<https://engineering.wustl.edu/Profiles/Pages/Jai-Rudra.aspx>)
PhD, Louisiana Tech University
Peptide-based biomaterials; immunoengineering; immunology of nanoscale aggregates; development of vaccines and immunotherapies

Jon Silva (<https://engineering.wustl.edu/Profiles/Pages/Jonathan-Silva.aspx>)
PhD, Washington University
Ion channel biophysics

Michael D. Vahey (<https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=113>)
PhD, Massachusetts Institute of Technology
Biophysical mechanisms of infectious disease; fluorescence microscopy; microfluidics

Senior Professor

Larry Taber (<https://bme.wustl.edu/faculty/Pages/Larry-Taber.aspx>)
PhD, Stanford University
Mechanics of growth and development; cardiac mechanics

Senior Lecturer

Patricia Widder (<https://bme.wustl.edu/faculty/Pages/Patricia-Widder.aspx>)
MS, Washington University

Lecturer

Noah Ledbetter (<https://bme.wustl.edu/faculty/Pages/Noah-Ledbetter.aspx>)
PhD, University of Utah

Senior Emeritus Professor

Frank Yin (<https://bme.wustl.edu/faculty/Pages/Frank-Yin.aspx>)
MD, PhD, University of California, San Diego

Degree Requirements

Please visit the following pages for information about the

- Master of Science (MS) in Biomedical Engineering (BME) (p. 24)
- Master of Engineering (MEng) in Biomedical Innovation (p. 24)
- Doctor of Philosophy (PhD) and Combined MD/PhD in BME (p. 25)
- Post-PhD Graduate Certificate in Medical Physics (p. 25)

Courses

Below are all BME graduate-level courses. Visit online course listings to view semester offerings for E62 BME (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E62&crslvl=5:8>).

E62 BME 501C BME Doctoral Seminar Series

This is a 1-unit credit option for BME students who attend regularly scheduled BME seminars (or approved substitute seminars). A satisfactory grade is obtained by submission of a two-page peer-reviewed paper written by one of the regularly scheduled BME seminar speakers whose seminar the student attended. Papers are to be submitted to the graduate student administrator for review by the director of doctoral studies. Prerequisites: Students must be current BME students in their second year and beyond in order to register. Credit 1 unit.

E62 BME 506 Seminar in Imaging Science and Engineering

This seminar course consists of a series of tutorial lectures on Imaging Science and Engineering with emphasis on applications of imaging technology. Students are exposed to a variety of imaging applications that vary depending on the semester, but may include multispectral remote sensing, astronomical imaging, microscopic imaging, ultrasound imaging, and tomographic imaging. Guest lecturers come from several parts of the university. This course is required of all students in the Imaging Science and Engineering program; the only requirement is attendance. This course is graded pass/fail. Prerequisite: admission to Imaging Science and Engineering program.

Same as E35 ESE 596
Credit 1 unit.

E62 BME 507 Radiological Physics and Dosimetry

This class is designed to construct a theoretical foundation for ionizing radiation dose calculations and measurements in a medical context and prepare graduate students for proper scientific presentations in the field of x-ray imaging and radiation therapy. Specifically, a student completing this course will be able to do the following: 1. Understand and apply key concepts specific to energy deposition for both ionizing photon interactions and transport in matter and for energetic charged particle interactions and transport in matter. Radiation sources include radioactivity, x-ray tubes, and linear accelerators. 2. Understand the theoretical details of ion-chamber based dosimetry and of both cavity-theory based (TG-21) and Monte-Carlo based (TG-51) clinical protocols. 3. Perform and present real-world style research projects as a group, and present these projects in a typical professional scientific format and style. 4. Achieve an appreciation of the history and potential future developments in ionizing radiation detection and dosimetry. Prerequisites: BS in physics or engineering and instructor approval.
Credit 3 units.

E62 BME 5071 Radiobiology

Effects of ionizing radiations on living cells and organisms, including physical, chemical, and physiological bases of radiation cytotoxicity, mutagenicity and carcinogenesis. Textbook: *Radiobiology for the Radiologist*. Eric Hall and Amato Giaccia. Two lectures per week. Prerequisites: graduate student standing and one year each of biology, physics and organic chemistry, or approval of instructor.
Credit 2 units.

E62 BME 5072 Radiation Therapy Physics

Ionizing radiation use in radiation therapy to cause controlled biological effects in cancer patients. Physics of the interaction of the various radiation modalities with body-equivalent materials, and physical aspects of clinical applications. Lecture and lab. Prerequisites: graduate student standing or permission of instructor.
Credit 3 units.

E62 BME 5073 Radiation Protection and Safety

This course will introduce concepts of radiation protection and safety. The focus will be on how to protect humans and environment from ionizing radiation. Special emphasis will be on radiological protection in clinics. Prerequisite: graduate student standing or permission of the instructor.
Credit 2 units.

E62 BME 523 Biomaterials Science

An understanding of the interactions between biological systems and artificial materials is of vital importance in the design of medical devices. This course will introduce the principles of biomaterials science, unifying knowledge from the fields of biology, materials science, surface science, and colloid science. The course will be taught from the primary scientific literature, focusing on the study of protein/surface interactions and hydrogel materials.
Credit 3 units. EN: TU

E62 BME 524 Tissue Engineering

This course integrates the principles and methods of engineering and life sciences toward the fundamental understanding of normal and pathological mammalian tissues especially as they relate to the development of biological substitutes to restore or improve tissue function. Current concepts and strategies including drug delivery, tissue and cell transplantation, and in vivo tissue regeneration will be introduced as well as their respective clinical applications. Prerequisites: BME 366; or MEMS 3410, Biol 2960 and 2970; or permission of the instructor.
Credit 3 units. EN: TU

E62 BME 527 Design of Artificial Organs

Medical devices that replace the function of one of the major organs in the body must usually interface with flowing blood. Examples include total artificial hearts, left ventricular assist devices, membrane oxygenators, hemodialysis systems and encapsulated endocrine cells. The design of these devices relies on integration of knowledge from a variety of fields, in particular computational fluid dynamics and blood rheology. We study the process by which a concept for a device eventually leads to a functioning, blood-contacting medical device, with most of the focus on the design of left ventricular assist devices. Students learn to use CAD to design blood pumping devices, test their designs via computational fluid dynamics, and 3D print and test their pumps with water. Prerequisite: BME 366 or equivalent course in Transport Phenomena (including momentum and mass transfer).
Credit 3 units. EN: TU

E62 BME 528 Translational Regenerative Medicine

This course provides students with an opportunity to connect basic research with applications in translation for several tissues/disease models. Course sessions will alternate between literature on basic mechanisms of development/stem cell biology and applications led by researchers or clinicians working in each area. Areas of focus will include cardiovascular development/congenital heart disease and arrhythmia, lung, endocrinology/diabetes, gut/intestinal disorders, musculoskeletal, neural (peripheral and brain), liver, hematology and eye. Emphasis on how discovery can be translated will be a major focus of the course. Students will be expected to review and present on primary literature in the field. Graduate standing is required. Prerequisites: graduate standing Engineering or DBBS.
Credit 3 units.

E62 BME 530A Molecular Cell Biology for Engineers

This course is designed for upper-level undergraduates and first-year graduate students with a background in engineering. This course covers the biology of cells of higher organisms: protein structure and function; cellular membranes and organelles; cell growth and oncogenic transformation; cellular transport, receptors and cell signaling; the cytoskeleton, the extracellular matrix and cell movement. Emphasis is placed on examples relevant to biomedical engineering. The course includes two lectures per week and one discussion section. In the discussion section, the emphasis is on experimental techniques used in cell biology and the critical analysis for primary literature. Note this course does not count for engineering topics credits and is meant to fulfill a life science requirement for engineering or physical sciences graduate students. Prerequisites: Biol 2960 and 2970 or graduate standing.
Credit 4 units.

E62 BME 533 Biomedical Signal Processing

Course designed for graduate students with little or no background in signal processing. Continuous-time and discrete-time application of signal processing tools to a variety of biomedical problems. Course topics include review of linear signals and systems theory, frequency transforms, sampling theorem, basis functions, linear filtering, feature extraction, parameter estimation and biological system modeling. Special emphasis will be placed on signal transduction and data acquisition. Additional topics include noise analysis of real-world biosignals, biological system identification, stochastic/chaotic/fractal/nonlinear processes in biological systems. Concepts learned in class will be applied using software tools to 1D biomedical signals such as biological rhythms, chemical concentrations, blood pressure, speech, EMG, ECG, EEG. Prerequisites: graduate standing or consent of instructor. Credit 3 units. EN: TU

E62 BME 537 Computational Molecular Biology

This course is a survey of algorithms and mathematical methods in biological sequence analysis (with a strong emphasis on probabilistic methods) and systems biology. Sequence analysis topics include introduction to probability, probabilistic inference in missing data problems, hidden Markov models (HMMs), profile HMMs, sequence alignment, and identification of transcription-factor binding sites. Systems biology topics include discovery of gene regulatory networks, quantitative modeling of gene regulatory networks, synthetic biology, and (in some years) quantitative modeling of metabolism. Prerequisite: CSE 131. Same as E81 CSE 587A. Credit 3 units.

E62 BME 538 Cell Signal Transduction

This class covers the elements of cell signal transduction important to human development, homeostasis and disease. Lectures are combined with primary literature review to cover canonical signaling and current topics within the field. Spatial, time and dose-dependent aspects of signaling are of particular focus. Topics include: G protein-coupled receptors, receptor tyrosine kinases, adhesion signaling, the MAPK cascade, lipid signaling, the DNA damage response, and autocrine, paracrine and juxtacrine signaling. Prerequisites: BME 530A or BME 5068. Credit 3 units.

E62 BME 550 Numerical Methods for Computational Modeling in Biomedicine

Advanced computational methods are required for the creation of biological models. Students will be introduced to the process of model development from beginning to end, which includes model formulation, how to solve and parameterize equations, and how to evaluate model success. To illustrate the potential of these methods, participants will systematically build a model to simulate a "real-life" biological system that is applicable to their research or interest. A mechanistic appreciation of the methods will be gained by programming the methods in a low-level language (C++) in a Linux environment. While extensive programming knowledge is not required, participants are likely to find that some programming background will be helpful. Students enrolled in the 550 graduate class will be required to complete a final project that incorporates the methods taught in class. Prerequisites: introductory programming course similar to E81 CSE 131. Same as E62 BME 450. Credit 3 units. EN: TU

E62 BME 5565 Mechanobiology of Cells and Matrices

At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions, and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor. Same as E37 MEMS 5565. Credit 3 units. EN: TU

E62 BME 559 Intermediate Biomechanics

This course covers several of the fundamental theories of solid mechanics that are needed to solve problems in biomechanics. The theories of nonlinear elasticity, viscoelasticity and poroelasticity are applied to a large range of biological tissues including bone, articular cartilage, blood vessels, the heart, skeletal muscle, and red blood cells. Other topics include muscle activation, the biomechanics of development and functional adaptation, and the mechanics of hearing. Prerequisites: BME 240 and ESE 318 and ESE 319 or equivalent, or permission of instructor. Credit 3 units. EN: TU

E62 BME 5610 Protein Structures and Dynamics

This course covers the concepts and methods involved in the analysis of protein structure, stability, folding and misfolding. Topics include protein structural elements, amyloid structure, intra- and intermolecular forces, folding pathways and intermediates, phi-value analysis, kinetics of protein folding and of amyloid formation, and their application to problems of bioengineering and biophysics. Two-thirds of the course will consist of lectures; the other third will be student seminars, in which each student presents a paper from primary literature and its concept and methodology that is discussed in detail. Prerequisites: BME 320B Bioengineering Thermodynamics or equivalent. Same as E62 BME 461. Credit 3 units. EN: TU

E62 BME 562 Mechanics of Growth and Development

This course applies the fundamental principles of solid mechanics to problems involving growth, remodeling and morphogenesis of cells, tissues and organs. Introduction to developmental biology, nonlinear elasticity, viscoelasticity and active contraction. Particular topics include cellular morphogenetic mechanisms, growth and development of the cardiovascular system, and adaptive remodeling of bone. Prerequisites: BME 240 or MEMS 241 or equivalent. Credit 3 units. EN: TU

E62 BME 564 Orthopaedic Biomechanics — Cartilage/Tendon

Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament;

applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisite: BME 240 or equivalent. *Note:* BME 590Z (BME 463/563) Orthopaedic Biomechanics — Bones and Joints is *not* a prerequisite. Same as E37 MEMS 5564
Credit 3 units. EN: TU

E62 BME 565 Biosolid Mechanics

Introduction to the mechanical behaviors of biological tissues of musculoskeletal, cardiac and vascular systems. Topics to be covered include static force analysis and nonlinear optimization theory; linearly elastic models for stress-strain analysis and solutions to relevant problems in bioelasticity; models of active structures (e.g., muscles); strain energy methods and nonlinear tissue behaviors; and introductory theory for finite element analysis. Emphasis will be placed on modeling stress-strain relations with relevance to biological tissues. Prerequisites: BME 240 or equivalent and ESE 318 and ESE 319.
Same as E62 BME 465
Credit 3 units. EN: TU

E62 BME 5702 Application of Advanced Engineering Skills for Biomedical Innovators

Students will work in small teams to apply core engineering skills covered in BME 5701 such as FEM, CAD, microcontroller programming, circuit design, data informatics, and app development to particular clinical needs or processes chosen by the instructing staff. Prerequisites: BME 5701 or permission of instructor.
Credit 3 units.

E62 BME 5711 Ideation of Biomedical Problems and Solutions

This course is part one of the year-long master's design sequence for the BME Master of Engineering. The course will begin with a boot camp primer of HIPAA certification, clinical etiquette, medical law, and intellectual property law. This will be followed by a rotation period of guided shadowing of clinicians. Following each rotation, students will review and present their findings, with a view toward problem solving and project generation. Three-fourths of the way through the course, students will form into teams, choose a master's project, and begin intensive study of their chosen problem or process. The final weeks of the course will focus on problem scope and definition, identification of creative alternatives, and consultation with experts in the field. Prerequisite: acceptance into the Master of Engineering program.
Credit 3 units.

E62 BME 5712 Implementation of Biomedical Solutions

This course is part two of the year-long master's design sequence for the BME Master of Engineering. Students will work in small groups to begin to design a solution to the problem identified in BME 5711. Options and alternatives will be evaluated and a best-choice solution will be chosen, based on an in-depth study of constraints upon the problem, including engineering materials, economic, safety, social, manufacturing, ethical, sustainability, and other requirements. Core skills such as FEM, CAD, circuit design, microcontroller programming, and 3-D printing will be applied to create first an alpha mockup for proof of concept, followed by a full working prototype by the

end of the semester. Prerequisites: BME 5711 or permission of instructor.
Credit 3 units.

E62 BME 5713 Translation of Biomedical Solutions to Products

This course is the third and final part of the year-long master's design course sequence. Through a repeated sequence of iteration, fabrication and verification, design teams will refine and optimize their master's design project, bringing it to completion. Prerequisites: BME 5712 or permission of instructor.
Credit 4 units.

E62 BME 572 Biological Neural Computation

This course considers the computations performed by the biological nervous system with a particular focus on neural circuits and population-level encoding/decoding. Topics include Hodgkin-Huxley equations; phase-plane analysis; reduction of Hodgkin-Huxley equations; models of neural circuits; plasticity and learning; and pattern recognition and machine learning algorithms for analyzing neural data. *Note:* Graduate students in psychology or neuroscience who are in the Cognitive, Computational and Systems Neuroscience curriculum pathway may register in Biol 5657 for 3 credits. For non-BME majors, conceptual understanding, and selection/application of right neural data analysis technique are stressed. Hence homework assignments/examinations for the two sections are different, however all students are required to participate in a semester-long independent project as part of the course. Prerequisites: calculus, differential equations, basic probability and linear algebra. Undergraduates need permission of the instructor. Biol 5657 prerequisites: permission from the instructor.
Credit 3 units. EN: TU

E62 BME 5722 Feasibility Evaluation of Biomedical Products

This is the second course of the Master of Engineering - Biomedical Innovation sequence in product development. Students will practice the steps in biomedical product development, including medical need validation, brainstorming initial solutions, market analysis, solution evaluation, regulatory, patent, and intellectual property concerns, manufacturability, risk assessment and mitigation, and global considerations. The course will focus on applying product development techniques to several real unmet medical needs; students will thus perform analysis and create reports and presentations for several different product solutions. Peer and faculty evaluations will provide feedback to improve individual technique. Local biomedical entrepreneurs will also visit to share their expertise and experiences. Prerequisite: admission to the Master of Engineering program.
Credit 2 units.

E62 BME 5723 Realization of Biomedical Products in the Marketplace

This course is the third in the MEng-BMI Biomedical Product Development sequence, focusing on the final stages of analysis to bring forth a leading solution concept. Solution concepts are screened for killer risks in the areas of intellectual property, regulatory, reimbursement, business models, and technical feasibility to identify viable concepts. From there, manufacturability and product specifications are evaluated against user and design requirements to select a concept that offers the highest value with lowest risk. Throughout the course, students will practice effective communication of risk

factors through pitch presentations and executive summary reports. In addition, specialists from the St. Louis entrepreneurial community will share their experiences as guest speakers. Prerequisites: BME 5722; MEng-BMI candidates only. Credit 1 unit.

E62 BME 5731 Business Foundations for Biomedical Innovators

For medical innovators, a successful translation from product to market will require careful strategy and an understanding of the steps needed to form and fund a biotech business, either as a new startup or as an extension of the product line of an existing company. This course will provide a first look at the steps in this process, including intellectual property concerns, R&D, clinical strategy, regulatory issues, quality management, reimbursement, marketing strategy, sales and distribution, operating plans, and approaches to funding. Prerequisites: MEng program. Credit 2 units.

E62 BME 5732 Entrepreneurship for Biomedical Innovators

This course will apply the concepts covered in BME 5731 in an interactive process that will provide practical experience. Topics of intellectual property, R&D, clinical strategy, regulatory issues, quality management, reimbursement, marketing strategy, sales and distribution, operating plans, and approaches to funding will be covered. Along with practical exercises, access to specialists and experts in these topics from the St. Louis entrepreneurial community will be provided as an integral part of the course. Prerequisites: BME 5731; MEng-BMI candidates only. Credit 2 units.

E62 BME 574 Quantitative Bioelectricity and Cardiac Excitation

Action potential generation, action potential propagation, source-field relationships in homogeneous and inhomogeneous media, models of cardiac excitation and arrhythmia, quantitative electrocardiography. Prerequisites: differential equations, Laplace transform, electromagnetic field theory (undergraduate level). Credit 3 units. EN: TU

E62 BME 575 Molecular Basis of Bioelectrical Excitation

Ion channels are the molecular basis of membrane excitability in all cell types, including neuronal, heart and muscle cells. This course presents the structure and the mechanism of function of ion channels at the molecular level. It introduces the basic principles and methods in the ion channel study as well as the structure-function relation of various types of channels. Exemplary channels that have been best studied are discussed to illustrate the current understanding. Prerequisites: knowledge of differential equations, electrical circuits and chemical kinetics. Credit 3 units. EN: TU

E62 BME 5771 Biomedical Product Development

Advances in science and technology have opened the health care field to innovation now more than any other time in history. Engineers and inventors can make real and rapid improvements to patient treatments, length of hospital stay, procedure time, cost containment, and accessibility to treatment. However, a successful transition from idea to implementation requires careful market analysis and strategy planning. This course will address the steps in this process, including personal and team strength assessment, medical need validation, brainstorming

initial solutions, market analysis, solution evaluation, regulatory, patent and intellectual property concerns, manufacturability, risk assessment and mitigation, and global considerations. Students will be expected to review resource material prior to coming to class in order to facilitate active class discussion and team-based application of the material during class; regular attendance will be key to course success. The course will focus on applying product development techniques to several real unmet medical needs; students will thus perform analysis and create reports and presentations for several different product solutions. Peer and faculty evaluations will provide feedback to improve individual technique. In addition, throughout the semester, local biomedical entrepreneurs will visit to share their expertise and experiences. Prerequisites: graduate or professional student standing or permission of the instructor. Credit 3 units.

E62 BME 5772 Biomedical Business Development

For medical innovators, a successful translation from product to market will require careful strategy and an understanding of the steps needed to form and fund a biotech business, either as a new startup or as an extension of the product line of an existing company. This course will address the steps in this process, including intellectual property concerns, R&D, clinical strategy, regulatory issues, quality management, reimbursement, marketing strategy, sales and distribution, operating plans, and approaches to funding. Prerequisites: graduate or professional student standing or permission of the instructor. Credit 3 units.

E62 BME 5799 Independent Study for Candidates in the Master of Engineering Program

Independent investigation on a topic of special interest. The student and mentor must justify the requested number of units. The MEng program director must approve the requested number of units. Credit variable, maximum 6 units.

E62 BME 5820 Fundamentals and Applications of Modern Optical Imaging

Analysis and application of modern optical imaging systems with emphasis on biological imaging. First part of course will focus on the physical principles underlying the operation of imaging systems and their mathematical models. Topics include ray optics (speed of light, refractive index, laws of reflection and refraction, plane surfaces, mirrors, lenses, aberrations), wave optics (amplitude and intensity, frequency and wavelength, superposition and interference, interferometry), Fourier optics (space-invariant linear systems, Huygens-Fresnel principle, angular spectrum, Fresnel diffraction, Fraunhofer diffraction, frequency analysis of imaging systems), and light-matter interaction (absorption, scattering, dispersion, fluorescence). Second part of course will compare modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students will evaluate and critique recent optical imaging literature. Prerequisites: ESE 318 and ESE 319 or their equivalents; ESE 330 or Physics 421 or equivalent. Same as E35 ESE 582. Credit 3 units. EN: TU

E62 BME 589 Biological Imaging Technology

This class develops a fundamental understanding of the physics and mathematical methods that underlie biological imaging and

critically examine case studies of seminal biological imaging technology literature. The physics section examines how electromagnetic and acoustic waves interact with tissues and cells, how waves can be used to image the biological structure and function, image formation methods and diffraction limited imaging. The math section examines image decomposition using basis functions (e.g., Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multidimensional imaging datasets, multivariate regression and statistical image analysis. Original literature on electron, confocal and two photon microscopy, ultrasound, computed tomography, functional and structural magnetic resonance imaging and other emerging imaging technology are critiqued.

Same as E35 ESE 589

Credit 3 units. EN: TU

E62 BME 5901 Integrative Cardiac Electrophysiology

Quantitative electrophysiology of the heart, integrating from the molecular level (ion channels, regulatory pathways, cell signaling) to the cardiac cell (action potential and calcium transient), multicellular tissue (cell-cell communication) and the whole heart. Prerequisite: permission of instructor.

Credit 3 units. EN: TU

E62 BME 5902 Cellular Neurophysiology

This course examines the biophysical concepts of synaptic function with the focus on the mechanisms of neural signal processing at synapses and elementary circuits. The course combines lectures and discussion sessions of primary research papers. Topics include synaptic and dendritic structure, electrical properties of axons and dendrites, synaptic transmission, rapid and long-term forms of synaptic plasticity, information analysis by synapses and basic neuronal circuits, principles of information coding, mechanisms of learning and memory, function of synapses in sensory systems, models of synaptic disease states such as Parkinson and Alzheimer's diseases. Additionally, a set of lectures is devoted to modern electrophysiological and imaging techniques, and modeling approaches to study synapses and neural circuits. Prerequisite: senior or graduate standing.

Credit 3 units. EN: TU

E62 BME 5903 Physical Methods for Biomedical Scientists

The course will introduce the spectrum of biophysical techniques used in biomedical sciences with a focus on advanced fluorescence spectroscopy. The first half of the course (January to spring break) will introduce the concepts behind techniques such as: dynamic light scattering, SPR, analytical ultracentrifugation size-exclusion and affinity chromatography, atomic force microscopy, fluorescence spectroscopy, FRET, FTIR, circular dichroism, fluorescence correlation spectroscopy, sub-diffraction microscopy. The second half of the course will be held as six 3 h block lab classes (Fridays 10 a.m.-1 p.m.) in which the students will use these techniques in experiments on protein folding, protein stability and amyloid formation. Prior attendance of BME 461 Protein Structure and Dynamics is encouraged. Because of limited room in the experimental lab, attendance will be limited to nine students. Prerequisite: senior or graduate standing.

Same as E62 BME 4903

Credit 3 units. EN: TU

E62 BME 591 Biomedical Optics I: Principles

This course covers the principles of optical photon transport in biological tissue. Topics include a brief introduction to biomedical optics, single-scatterer theories, Monte Carlo modeling of photon transport, convolution for broad-beam responses, radiative transfer equation and diffusion theory, hybrid Monte Carlo method and diffusion theory, and sensing of optical properties and spectroscopy. Prerequisite: differential equations.

Credit 3 units. EN: TU

E62 BME 5911 Cardiovascular Biophysics Journal Club

This journal club is intended for beginning graduate students, advanced undergraduates and MSTP students with a background in the quantitative sciences (engineering, physics, math, chemistry, etc.). The subjects covered are inherently multidisciplinary. We review landmark and recent publications in quantitative cardiovascular physiology, mathematical modeling of physiologic systems and related topics such as chaos theory and nonlinear dynamics of biological systems. Familiarity with calculus, differential equations and basic engineering/thermodynamic principles is assumed. Knowledge of anatomy/physiology is optional.

Credit 1 unit.

E62 BME 5913 Molecular Systems Biology: Computation & Measurements for Understanding Cell Physiology and Disease

Systems-level measurements of molecules in cells and tissues harbor the promise to identify the ways in which tissues develop, maintain, age, and become diseased. This class will introduce the systems-level measurement techniques for capturing molecular information and the mathematical and computational methods for harnessing the information from these measurements to improve our understanding of cell physiology and disease. This is a practical class, which involves implementation of the concepts in MATLAB and will be applied to existing, real data from published journal articles. Molecular topics will include: gene expression, microRNA, proteins, post-translational modifications, drugs, and splicing. Computational/mathematical topics covered will include: statistical inference, dimensionality reduction techniques, unsupervised and supervised machine learning, and graph-based techniques. Prerequisites: A working knowledge of molecular biology, linear algebra, and statistics is required.

Credit 3 units. EN: TU

E62 BME 593 Computational Methods for Inverse Problems

Inverse problems are ubiquitous in science and engineering, and form the basis for modern imaging methods. This course will introduce students to the mathematical formulation of inverse problems and modern computational methods employed to solve them. Specific topics covered will include regularization theory, compressive sampling, and a survey of relevant numerical optimization methods. The application of these methods to tomographic imaging problems will be addressed in detail. Prerequisites: ESE 318, 319, 326, 351.

Same as E62 BME 493

Credit 3 units. EN: TU

E62 BME 594 Ultrasound Imaging

Introduce basic principles of ultrasound imaging, diagnostic ultrasound imaging system, clinical applications, and emerging technologies in industry. Prerequisite: ESE 351.

Same as E62 BME 494
Credit 3 units. EN: TU

E62 BME 595 Drug Delivery Systems: Principles and Applications

Drug delivery is a promising approach for transporting pharmaceutical treatments in the body to safely achieve the desired therapeutic effect, while reducing the undesired side effects. This course will introduce students to the fundamental concepts of drug pharmacokinetics and dynamics, the biological and physiochemical principles drug delivery systems are based on, and the advantages of such delivery systems. Additionally, we will introduce the design and development of advanced drug delivery platforms such as nano-carriers, cell/gene delivery systems, drug-polymer conjugates and their relevant clinical applications. Finally, we will be having guest speakers from the industry, the university, as well as the office of technology management for Interdisciplinary Innovation & Entrepreneurship. Credit 3 units.

E62 BME 599 Master's Research

Credit variable, maximum 6 units.

E62 BME 600 Doctoral Research

Credit variable, maximum 12 units.

E62 BME 601 Research Rotation for BME Doctoral Students

E62 BME 601C Research Rotation for BME Doctoral Students

Credit 3 units.

E62 BME 602 Teaching Assistantship - Basic

This is a pass/fail course for the fulfillment of the basic teaching requirement which is required for the PhD degree. A form obtained from the BME department must be submitted to the instructor at the end of the semester for approval in order to receive a grade.

E62 BME 603 Teaching Assistantship - Advanced

This is a pass/fail course for the fulfillment of the advanced teaching requirement which is required for the PhD degree. A form obtained from the BME department must be submitted to their thesis mentor upon completion of requirements for approval in order to receive a grade.

E62 BME 883 Master's Continuing Student Status

Master of Science (MS) in Biomedical Engineering (BME)

A core curriculum that must be satisfied by all graduate MS students consists of the following:

- Two graduate-level courses in life sciences
- One graduate-level course in mathematics

- One graduate-level course in computer science
- Three BME courses from the approved course list

Please visit the Policies and Regulations Guide located on the Biomedical Engineering (BME) website (<http://bme.wustl.edu/graduate/ms/Pages/default.aspx>) for a comprehensive list of the approved and core courses.

Candidates for the MS must accumulate a total of 30 graduate course credits beyond the bachelor's degree. Only 6 of the 30 graduate course credits may be transferred from another university. There are two options: thesis and non-thesis.

Thesis option

For this option, a minimum of 24 graduate course credits is required, with the balance being thesis research. The courses must fulfill the core curriculum requirement (courses found in the Policies and Regulations Guide on the BME website (<http://bme.wustl.edu/graduate/ms/Pages/default.aspx>)).

The remainder of the course work is generally driven by the student's research interest. Upon completion of the thesis, the candidate must pass an oral defense conducted by their thesis committee. This will consist of a public presentation followed by questions from the committee. Candidates must have a cumulative grade point average of 2.7 or better to receive the degree.

Non-Thesis option

Candidates must accumulate a total of 30 graduate credits, have a cumulative grade point average of 2.7 or better, and satisfy the core curriculum requirement (courses found in the Policies and Regulations Guide on the BME website (<http://bme.wustl.edu/graduate/ms/Pages/default.aspx>)). The balance of the course credits should be selected with a view toward coherence reflecting a specialization in a research area.

Graduate-level courses given by other departments and schools may be substituted for courses in the approved list with the permission of the Director of Master's Studies. The full list of approved courses can be found in the Policies and Regulations Guide on the BME website (<http://bme.wustl.edu/graduate/ms/Pages/default.aspx>).

Master of Engineering (MEng) in Biomedical Innovation

This 12-month professional graduate degree is designed for students interested in entrepreneurship or "intra"preneurship for advanced placement within a medical device company, other health care company or running their own startup. It is a team-based approach in which students develop the engineering, design and business skills to solve an unmet clinical need.

The program consists of 30 units that are distributed into five areas:

- Engineering Skills (6 units)
- Master Design (10 units)
- Biomedical Product Development (4 units)
- Biomedical Business Development (4 units)
- Targeted Electives (6 units)

The Master of Engineering in Biomedical Innovation (MEng-BMI) program has a list of specific courses that are required. These are found in the Courses (p. 18) section in the E62 BME 57## sequence. Visit the Policies and Regulations guide located on the BME website (<http://bme.wustl.edu/graduate/meng/Pages/default.aspx>) for the MEng-BMI program timeline.

PhD and Combined MD/PhD in Biomedical Engineering

The department offers programs leading to the Doctor of Philosophy (PhD) in Biomedical Engineering and combined MD/PhD degrees. The latter degree is given jointly with the School of Medicine.

The doctoral degree requires a minimum of 72 credits beyond the bachelor's level, with a minimum of 36 being course credits (including the core curriculum) and a minimum of 24 credits of doctoral dissertation research.

The core curriculum that must be satisfied by all PhD students consists of the following:

- One graduate-level course in life science from an approved list
- One graduate-level course in mathematics from approved list
- One graduate-level course in computer science from approved list or exemption by proficiency
- Four BME courses from an approved list

Please visit the Biomedical Engineering (BME) website (<https://bme.wustl.edu/graduate/phd/Pages/default.aspx>) for a comprehensive list of the approved courses.

Up to 9 credits of BME 601C Research Rotation (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E62&crs=601C>) and/or BME 501C Graduate Seminar (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E62&crs=501C>) may be counted toward the 36 credits of graduate courses required for the PhD, so a total of 27 additional credits (~nine courses including the core curriculum) are required for the PhD. Up to two 400-level courses may be counted toward the nine courses required for the PhD (not including independent study courses, journal clubs or seminar-based courses). Graduate courses may be transferred in (up to 24 credits) but must be evaluated and approved by the director of doctoral studies. The evaluation and approval may occur at any time, but course transfer does not become official until after one year in residence at Washington University.

Students seeking the **PhD in Biomedical Engineering** enroll in two to three courses each semester and participate in one or two laboratory rotations in the first year. Ten months after they enroll in the program, students take their oral qualifying exam consisting of a presentation of their research done to date in the mentor's laboratory followed by an oral exam addressing any issues directly related to their rotation report or their oral presentation. Upon successfully passing the qualifying examination, they advance to candidacy and complete the balance of their requirements. During the second and third years, students complete their remaining courses, participate in one semester of a mentored teaching experience, and begin their thesis research. By the end of the third year, students must complete their thesis proposal. Students must also complete one accepted and one submitted first author publication and complete a dissertation.

Students pursuing the combined **MD/PhD in Biomedical Engineering** must complete the degree requirements in both schools. MD/PhD students typically complete the first two years of the medical school pre-clinical curriculum while also performing one or more research rotations, then the remaining requirements for the doctoral degree, and finally the clinical training years of the medical degree. The department generally gives graduate course credits for some of the medical school courses toward fulfillment of course requirements for the PhD degree. This is arranged on an individual basis between the student, their academic adviser, and the director of doctoral studies.

Post-PhD Graduate Certificate in Medical Physics

Students seeking the **Postdoctoral Medical Physics Certificate** must complete 18 course credits, which can be completed in 2-4 semesters. A Medical Physics Certificate allows a student with a PhD in physics or other related subjects to apply for medical physics residency programs and seek a career as a clinical medical physicist.

Required Courses

Code	Title	Units
Biol 4580	Principles of Human Anatomy and Development	3
BME 507	Radiological Physics and Dosimetry	3
BME 589/ESE 589	Biological Imaging Technology	3
BME 5071	Radiobiology	2
BME 5072	Radiation Therapy Physics	3
BME 5073	Radiation Protection and Safety	2
BME 5074	Advance Clinical Medical Physics Lab	2
Total Units		18

Additional Information

- To be admitted to the Medical Physics Certificate program, a candidate must have a PhD in physics, nuclear engineering or a similar field and submit a formal application.
- Candidates must have three undergraduate-level or graduate-level advanced physics courses to be considered for admission.

Contact Information

Contact: Rao Khan
Email: khanrf@wustl.edu
Website: <https://radonc.wustl.edu/education/post-phd-graduate-certificate-in-medical-physics/>

Computer Science & Engineering

In the past two decades, society has experienced unprecedented growth in digital technology. This revolution continues to redefine our way of life, culture and economy. Computer science and engineering education plays an irreplaceable role in this trend by preparing future technology leaders and innovators. It opens our minds to new horizons, unlocks doors to a broad range of career paths, accelerates professional advancement, and exposes us to ideas that are advancing the frontiers of science and technology beyond the field of computing. Alumni and students continually remind us that pursuing a degree in the Department of Computer Science & Engineering is an experience rarely matched elsewhere.

Master's Programs

The Department of Computer Science & Engineering offers four master's degrees: **Master of Science in Computer Science**, **Master of Science in Computer Engineering**, **Master of Science in Cybersecurity Engineering**, and **Master of Engineering in Computer Science and Engineering**. We accept both full-time and part-time students offering class schedules that are flexible enough for a part-time student but provide enough classes for students to attend full-time. Obtaining a master's degree from the Department of Computer Science & Engineering can be done as a pure course option (MS in Computer Science or Computer Engineering degrees only) or can incorporate a specialized research experience. Master's research is a great way for our students to easily transition into future doctoral studies. Graduates of our program are also prepared to enter the industry with many accepting positions at companies like Boeing, Google and Microsoft. Applicants to our master's programs are expected to have completed an undergraduate degree. A major or minor in computer science or computer engineering is helpful, though not required.

Background requirements are listed within each degree program, along with options for meeting them.

PhD Programs

The Department of Computer Science & Engineering offers **PhD programs in Computer Science and in Computer Engineering**. Computer Science research encompasses the fundamentals of software and algorithm design, machine learning and bioinformatics, visual and cyber-physical computing, and human-computer interaction. Computer Engineering focuses on the interaction of software and hardware in the design of computing systems and networks. Our research groups have extensive interdisciplinary ties across the university, with collaborations in medicine, science, the humanities and social work. Recent graduates have accepted research and teaching faculty positions, and research and engineering positions in leading technology companies.

Both PhD programs require a combination of courses, research and teaching. The required courses are often completed early in the program since students are integrated into research groups in their first year and the program emphasis is on creative research. The program has milestones with both written and oral components that provide structure to the five- to six-year degree. The program considers applicants with either bachelor's or master's degrees and has had successful applicants in the past whose background is outside of computer science.

Phone: 314-935-6132
Email: admissions@cse.wustl.edu
Website: <https://cse.wustl.edu/graduate/programs>

Faculty

Chair

Roch Guérin (<https://engineering.wustl.edu/Profiles/Pages/Roch-Gu%C3%A9rin.aspx>)

Harold B. and Adelaide G. Welge Professor of Computer Science

PhD, California Institute of Technology

Computer networks and communication systems

Professors

Sanjoy Baruah (<https://engineering.wustl.edu/Profiles/Pages/Sanjoy-Baruah.aspx>)

PhD, University of Texas at Austin

Real-time and safety-critical system design, cyber-physical systems, scheduling theory, resource allocation and sharing in distributed computing environments

Aaron Bobick (<https://engineering.wustl.edu/Profiles/Pages/Aaron-Bobick.aspx>)

James M. McKelvey Professor and Dean
PhD, Massachusetts Institute of Technology
Computer vision, graphics, human-robot collaboration

Michael R. Brent (<https://engineering.wustl.edu/Profiles/Pages/Michael-Brent.aspx>)

Henry Edwin Sever Professor of Engineering
PhD, Massachusetts Institute of Technology
Systems biology, computational and experimental genomics, mathematical modeling, algorithms for computational biology, bioinformatics

Jeremy Buhler (<https://engineering.wustl.edu/Profiles/Pages/Jeremy-Buhler.aspx>)

PhD, Washington University
Computational biology, genomics, algorithms for comparing and annotating large biosequences

Roger D. Chamberlain (<https://engineering.wustl.edu/Profiles/Pages/Roger-Chamberlain.aspx>)

DSc, Washington University
Computer engineering, parallel computation, computer architecture, multiprocessor systems

Yixin Chen (<https://engineering.wustl.edu/Profiles/Pages/Yixin-Chen.aspx>)

PhD, University of Illinois at Urbana-Champaign
Mathematical optimization, artificial intelligence, planning and scheduling, data mining, learning data warehousing, operations research, data security

Patrick Crowley (<https://engineering.wustl.edu/Profiles/Pages/Patrick-Crowley.aspx>)

PhD, University of Washington
Computer and network systems, network security

Ron K. Cytron (<https://engineering.wustl.edu/Profiles/Pages/Ron-Cytron.aspx>)

PhD, University of Illinois at Urbana-Champaign
Programming languages, middleware, real-time systems

Christopher D. Gill (<https://engineering.wustl.edu/Profiles/Pages/Christopher-Gill.aspx>)

DSc, Washington University
Parallel and distributed real-time embedded systems, cyber-physical systems, concurrency platforms and middleware, formal models and analysis of concurrency and timing

Raj Jain (<https://engineering.wustl.edu/Profiles/Pages/Raj-Jain.aspx>)

Barbara J. & Jerome R. Cox Jr. Professor of Computer Science
PhD, Harvard University
Network security, blockchains, medical systems security, industrial systems security, wireless networks, unmanned aircraft systems, internet of things, telecommunications networks, traffic management

Tao Ju (<https://engineering.wustl.edu/Profiles/Pages/Tao-Ju.aspx>)

PhD, Rice University
Computer graphics, visualization, mesh processing, medical imaging and modeling

Chenyang Lu (<https://engineering.wustl.edu/Profiles/Pages/Chenyang-Lu.aspx>)

Fullgraf Professor in the Department of Computer Science & Engineering
PhD, University of Virginia
Internet of things, real-time, embedded, and cyber-physical systems, cloud and edge computing, wireless sensor networks

Weixiong Zhang (<https://engineering.wustl.edu/Profiles/Pages/Weixiong-Zhang.aspx>)

PhD, University of California, Los Angeles
Computational biology, genomics, machine learning and data mining, and combinatorial optimization

Associate Professors

Kunal Agrawal (<https://engineering.wustl.edu/Profiles/Pages/Kunal-Agrawal.aspx>)

PhD, Massachusetts Institute of Technology
Parallel computing, cyber-physical systems & sensing, theoretical computer science

Sanmay Das (<https://engineering.wustl.edu/Profiles/Pages/Sanmay-Das.aspx>)

PhD, Massachusetts Institute of Technology
Design of algorithms for complex environments, computational social science, machine learning

Caitlin Kelleher (<https://engineering.wustl.edu/Profiles/Pages/Caitlin-Kelleher.aspx>)

Hugo F. & Ina Champ Urbauer Career Development Associate Professor
PhD, Carnegie Mellon University
Human-computer interaction, programming environments, and learning environments

William D. Richard (<https://engineering.wustl.edu/Profiles/Pages/William-Richard.aspx>)

PhD, University of Missouri-Rolla
Ultrasonic imaging, medical instrumentation, computer engineering

Yevgeniy Vorobeychik (<https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=185>)

PhD, University of Michigan
Artificial intelligence, machine learning, computational economics, security and privacy, multi-agent systems

Assistant Professors

Ayan Chakrabarti (<https://engineering.wustl.edu/Profiles/Pages/Ayan-Chakrabarti.aspx>)
PhD, Harvard University
Computer vision computational photography, machine learning

Roman Garnett (<https://engineering.wustl.edu/Profiles/Pages/Roman-Garnett.aspx>)
PhD, University of Oxford
Active learning (especially with atypical objectives), Bayesian optimization, and Bayesian nonparametric analysis

Chien-Ju Ho (<https://engineering.wustl.edu/Profiles/Pages/Chien-Ju-Ho.aspx>)
PhD, University of California, Los Angeles
Design and analysis of human-in-the-loop systems, with techniques from machine learning, algorithmic economics, and online behavioral social science

Brendan Juba (<https://engineering.wustl.edu/Profiles/Pages/Brendan-Juba.aspx>)
PhD, Massachusetts Institute of Technology
Theoretical approaches to artificial intelligence founded on computational complexity theory and theoretical computer science more broadly construed

Ulugbek Kamilov (<https://engineering.wustl.edu/Profiles/Pages/Ulugbek-Kamilov.aspx>)
PhD, École Polytechnique Fédérale de Lausanne, Switzerland
Computational imaging, image and signal processing, machine learning and optimization

Brian Kocoloski (<https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=115>)
PhD, University of Pittsburgh
Scalable parallel computing, cloud computing, operating systems, virtualization

Angelina Lee (<https://engineering.wustl.edu/Profiles/Pages/I-Ting-Angelina-Lee.aspx>)
PhD, Massachusetts Institute of Technology
Designing linguistics for parallel programming, developing runtime system support for multithreaded software, and building novel mechanisms in operating systems and hardware to efficiently support parallel abstractions

Alvitta Ottley (<https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=109>)
PhD, Tufts University
Designing personalized and adaptive visualization systems, including information visualization, human-computer interaction, visual analytics, individual differences, personality, user modeling and adaptive interfaces

William Yeoh (<https://engineering.wustl.edu/Profiles/Pages/William-Yeoh.aspx>)
PhD, University of Southern California
Artificial intelligence, multi-agent systems, distributed constraint optimization, planning and scheduling

Miaomiao Zhang (<https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=183>)
PhD, University of Utah
Medical image analysis, statistical modeling, and machine learning

Ning Zhang (<https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=182>)
PhD, Virginia Polytechnic Institute and State University
Medical imaging

Professor of the Practice

Dennis Cosgrove (<https://cse.wustl.edu/faculty/Pages/Dennis-Cosgrove.aspx>)
BS, University of Virginia
Programming environments and parallel programming

Lecturers

Marion Neumann (<https://cse.wustl.edu/faculty/Pages/Marion-Neumann.aspx>)
PhD, University of Bonn, Germany
Machine learning with graphs; solving problems in agriculture and robotics

Jonathan Shidal (<https://cse.wustl.edu/faculty/Pages/Jon-Shidal.aspx>)
PhD, Washington University
Computer architecture and memory management

Douglas Shook (<https://cse.wustl.edu/faculty/Pages/Doug-Shook.aspx>)
MS, Washington University
Imaging sensor design, compiler design and optimization

William Siever (<https://cse.wustl.edu/faculty/Pages/Bill-Siever.aspx>)
Principal Lecturer
PhD, Missouri University of Science and Technology

Todd Sproull (<https://cse.wustl.edu/faculty/Pages/Todd-Sproull.aspx>)
PhD, Washington University
Computer networking and mobile application development

Senior Professors

Jerome R. Cox Jr.
ScD, Massachusetts Institute of Technology
Computer system design, computer networking, biomedical computing

Mark A. Franklin

Hugo F. and Ina Champ Urbauer Professor of Engineering
PhD, Carnegie Mellon University
Computer architecture, systems analysis and parallel processing, storage systems design

Jonathan S. Turner

PhD, Northwestern University
Design and analysis of internet routers and switching systems, networking and communications, algorithms

Professors Emeriti

Takayuki D. Kimura

PhD, University of Pennsylvania
Communication and computation, visual programming

Seymour V. Pollack

MS, Brooklyn Polytechnic Institute
Intellectual property, information systems

Degree Requirements

Please visit to the following pages for information about the

- Master of Science (MS) in Computer Science (p. 37)
- Master of Science (MS) in Computer Engineering (p. 37)
- Master of Science (MS) in Cybersecurity Engineering (p. 38)
- Master of Engineering (MEng) in Computer Science and Engineering (p. 39)
- Certificate in Data Mining and Machine Learning (p. 39)
- Doctor of Philosophy (PhD) in Computer Science or Computer Engineering (p. 40)

Courses

Visit online course listings to view semester offerings for E81 CSE (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E81&crslvl=5:8>).

E81 CSE 500 Independent Study

Credit variable, maximum 3 units.

E81 CSE 501N Introduction to Computer Science

An introduction to software concepts and implementation, emphasizing problem solving through abstraction and decomposition. Introduces processes and algorithms, procedural abstraction, data abstraction, encapsulation, and object-oriented programming. Recursion, iteration, and simple data structures are covered. Concepts and skills are mastered through programming projects, many of which employ graphics to enhance conceptual understanding. Java, an object-oriented programming language, is the vehicle of exploration. Active-learning sessions are conducted in a studio setting in which students interact with each other and the professor to solve problems collaboratively. Prerequisites: Comfort with algebra and geometry at the high school level is assumed. Patience, good planning, and organization will promote success. This course assumes no prior experience with programming.

Same as E81 CSE 131

Credit 3 units. BU: SCI EN: TU

E81 CSE 502N Data Structures and Algorithms

Study of fundamental algorithms, data structures, and their effective use in a variety of applications. Emphasizes importance of data structure choice and implementation for obtaining the most efficient algorithm for solving a given problem. A key component of this course is worst-case asymptotic analysis, which provides a quick and simple method for determining the scalability and effectiveness of an algorithm. Prerequisite: CSE 240.

Same as E81 CSE 247

Credit 3 units. EN: TU

E81 CSE 503S Rapid Prototype Development and Creative Programming

This course uses web development as a vehicle for developing skills in rapid prototyping. Students acquire the skills to build a Linux web server in Apache, to write a website from scratch in PHP, to run an SQL database, to perform scripting in Python, to employ the AngularJS web framework, and to develop modern web applications in client-side and server-side JavaScript. The course culminates with a creative project in which students are able to synthesize the course material into a project of their own interest. The course implements an interactive studio format: After a formal presentation of a topic, students develop a related project under the supervision of the instructor. Prerequisite: CSE 131.

Same as E81 CSE 330S

Credit 3 units. EN: TU

E81 CSE 504N Object-Oriented Software Development Laboratory

Intensive focus on practical aspects of designing, implementing and debugging software, using object-oriented, procedural, and generic programming techniques. The course emphasizes familiarity and proficiency with a wide range of C++ language features through hands-on practice completing studio exercises and lab assignments, supplemented with readings and summary presentations for each session. Prerequisites: CSE 247.

Same as E81 CSE 332S

Credit 3 units. EN: TU

E81 CSE 505N Introduction to Digital Logic and Computer Design

Introduction to design methods for digital logic and fundamentals of computer architecture. Boolean algebra and logic minimization techniques; sources of delay in combinational circuits and effect on circuit performance; survey of common combinational circuit components; sequential circuit design and analysis; timing analysis of sequential circuits; use of computer-aided design tools for digital logic design (schematic capture, hardware description languages, simulation); design of simple processors and memory subsystems; program execution in simple processors; basic techniques for enhancing processor performance; configurable logic devices. Prerequisite: CSE 131.

Same as E81 CSE 260M

Credit 3 units. EN: TU

E81 CSE 507A Technology Entrepreneurship

This is a course for students who plan to be, or work with, entrepreneurs. An entrepreneurial mindset is needed to create or

grow economically viable enterprises, be they new companies, new groups within companies, or new university laboratories. This course aims to cultivate an entrepreneurial perspective with particular emphasis on information technology (IT)-related activities. The course is jointly offered for business and CSE students, allowing for acculturation between these disciplines. In addition to an introductory treatment of business and technology fundamentals, course topics will include: business ethics, opportunity assessment, team formation, financing, intellectual property, and technology transfer. The course will feature significant participant and guest instruction from experienced practitioners. Prerequisites: none.
Credit 3 units.

E81 CSE 511A Introduction to Artificial Intelligence

The discipline of artificial intelligence (AI) is concerned with building systems that think and act like humans or rationally on some absolute scale. This course is an introduction to the field, with special emphasis on sound modern methods. The topics include knowledge representation, problem solving via search, game playing, logical and probabilistic reasoning, planning, dynamic programming, and reinforcement learning. Programming exercises concretize the key methods. The course targets graduate students and advanced undergraduates. Evaluation is based on written and programming assignments, a midterm exam and a final exam. Prerequisites: CSE 247, ESE 326, Math 233.
Credit 3 units.

E81 CSE 513T Theory of Artificial Intelligence and Machine Learning

Mathematical foundations for Artificial Intelligence and Machine Learning. An introduction to the PAC-Semantics ("Probably Approximately Correct") as a common semantics for knowledge obtained from learning and declarative sources, and the computational problems underlying the acquisition and processing of such knowledge. We emphasize the design and analysis of efficient algorithms for these problems, and examine for which representations these problems are known or believed to be tractable. Prerequisite: CSE 347.
Credit 3 units. EN: TU

E81 CSE 514A Data Mining

With the vast advancement in science and technology, data acquisition in large quantities are routinely done in many fields. Examples of large data include various types of data on the internet, high-throughput sequencing data in biology and medicine, extraterrestrial data from telescopes in astronomy, and images from surveillance cameras in security. Mining a large amount of data through data mining has become an effective means to extracting knowledge from data. This course introduces the basic concepts and methods for data mining and provides hands-on experience for processing, analyzing and modeling structured and unstructured data. Homework problems, exams and programming assignments will be administered throughout the course to enhance learning. Prerequisites: CSE 247 and ESE 326 (or Math 3200).
Credit 3 units. EN: TU

E81 CSE 515T Bayesian Methods in Machine Learning

This course will cover machine learning from a Bayesian probabilistic perspective. Bayesian probability allows us to model and reason about all types of uncertainty. The result is a powerful, consistent framework for approaching many problems

that arise in machine learning, including parameter estimation, model comparison, and decision making. We will begin with a high-level introduction to Bayesian inference, then proceed to cover more-advanced topics. These will include inference techniques (exact, MAP, sampling methods, the Laplace approximation, etc.), Bayesian decision theory, Bayesian model comparison, Bayesian nonparametrics, and Bayesian optimization. Prerequisites: CSE 417T.
Credit 3 units. EN: TU

E81 CSE 516A Multi-Agent Systems

This course introduces the fundamental techniques and concepts needed to study multi-agent systems, in which multiple autonomous entities with different information sets and goals interact. We will study algorithmic, mathematical, and game-theoretic foundations, and how these foundations can help us understand and design systems ranging from robot teams to online markets to social computing platforms. Topics covered may include game theory, distributed optimization, multi-agent learning and decision-making, preference elicitation and aggregation, mechanism design, and incentives in social computing systems. Prerequisites: CSE 347 (may be taken concurrently), ESE 326 (or Math 3200), and Math 233 or equivalents. Some prior exposure to artificial intelligence, machine learning, game theory, and microeconomics may be helpful, but is not required.
Credit 3 units. EN: TU

E81 CSE 517A Machine Learning

This course assumes a basic understanding of machine learning and covers advanced topics at the frontier of the field in-depth. Topics to be covered include kernel methods (support vector machines, Gaussian processes), neural networks (deep learning), and unsupervised learning. Depending on developments in the field, the course will also cover some advanced topics, which may include learning from structured data, active learning, and practical machine learning (feature selection, dimensionality reduction). Prerequisites: CSE 417T.
Credit 3 units. EN: TU

E81 CSE 518A Crowdsourcing and Human Computation

This course is an exploration of the opportunities and challenges of crowdsourcing and human computation, which are emerging fields that examine how humans can help solve problems that computers cannot solve yet. We will explore ways in which techniques from machine learning, game theory, optimization, online behavioral social science, and human-computer interactions can be used to model and analyze crowd-powered systems such as crowdsourcing markets, prediction markets, and user-generated content platforms. Prerequisites: CSE 247, ESE 326, and Math 233.
Credit 3 units.

E81 CSE 519T Advanced Machine Learning

This course provides a close look at advanced machine learning algorithms — their theoretical guarantees (computational learning theory) and tricks to make them work in practice. In addition, this course focuses on more specialized learning settings, including unsupervised learning, semi-supervised learning, domain adaptation, multi-task learning, structured prediction, metric learning and learning of data representations. Learning approaches may include graphical models, non-parametric Bayesian statistics, and technical topics such as sampling, approximate inference and non-linear function

optimization. Mathematical maturity and general familiarity of machine learning is required. Prerequisites: CSE 517A, CSE 511A, and CSE 571A.
Credit 3 units. EN: TU

E81 CSE 520S Real-Time Systems

This course covers software systems and network technologies for real-time applications such as automobiles, avionics, industrial automation and Internet of Things. Topics include real-time scheduling, real-time operating systems and middleware, Quality of Service, industrial networks and real-time cloud computing. Prerequisite: CSE 422S.
Credit 3 units. EN: TU

E81 CSE 521S Wireless Sensor Networks

Dense collections of smart sensors networked to form self-configuring pervasive computing systems provide a basis for a new computing paradigm that challenges many classical approaches to distributed computing. Naming, wireless networking protocols, data management and approaches to dependability, real-time, security and middleware services all fundamentally change when confronted with this new environment. Embedded sensor networks and pervasive computing are among the most exciting research areas with many open research questions. This class studies a large number of research papers that deal with various aspects of wireless sensor networks. Students perform a project on a real wireless sensor network composed of tiny devices each consisting of sensors, a radio transceiver and a microcontroller. Prerequisite: CSE 422S.
Credit 3 units. EN: TU

E81 CSE 522S Advanced Operating Systems

This course offers an in-depth hands-on exploration of core OS abstractions, mechanisms and policies, with an increasing focus on understanding and evaluating their behaviors and interactions. Readings, lecture material, studio exercises, and lab assignments are closely integrated in an active-learning environment in which students gain experience and proficiency writing, tracing, and evaluating user-space and kernel-space code. Topics include: inter-process communication, real-time systems, memory forensics, file-system forensics, timing forensics, process and thread forensics, hypervisor forensics, and managing internal or external causes of anomalous behavior. Prerequisite: CSE 422S.
Credit 3 units. EN: TU

E81 CSE 523S Systems Security

This course examines the intersection between computer design and information security. While performance and efficiency in digital systems have improved markedly in recent decades, computer security has worsened overall in this time frame. To understand why, we will explore the role that design choices play in the security characteristics of modern computer and network systems. Students will use and write software to illustrate mastery of the material. Projects will include identifying security vulnerabilities, exploiting vulnerabilities, and detecting and defending against exploits. Prerequisite: CSE 361S.
Credit 3 units. EN: TU

E81 CSE 530S Database Management Systems

A study of data models and the database management systems that support these data models. The design theory for databases

is developed and various tools are utilized to apply the theory. General query languages are studied and techniques for query optimization are investigated. Integrity and security requirements are studied in the context of concurrent operations on a database, where the database may be distributed over one or more locations. The unique requirements for engineering design databases, image databases, and long transaction systems are analyzed. Prerequisite: CSE 247.
Credit 3 units.

E81 CSE 531S Theory of Compiling and Language Translation

Algorithms and intermediate representations for automatic program analysis are examined, with an emphasis on practical methods and efficient engineering of program optimization and transformations. The course includes a thorough treatment of monotone data flow frameworks: a mathematical model in which most optimization problems can be specified and solved. The course primarily covers optimizations that are applicable to any target architecture; however, optimizations specific to parallel, distributed and storage-hierarchical systems also are discussed. Prerequisite: CSE 431S or CSE 425S.
Credit 3 units. EN: TU

E81 CSE 532S Advanced Multiparadigm Software Development

Intensive focus on advanced design and implementation of concurrent and distributed system software in C++. Topics covered include concurrency and synchronization features and software architecture patterns. Prerequisites: CSE 332S or graduate standing and strong familiarity with C++; and CSE 422S.
Credit 3 units. EN: TU

E81 CSE 536S Distributed System Design: Models and Languages

Modern computing environments are highly distributed. This has been the result of major advances in networking technology and their rapid assimilation by a society that functions in a highly distributed and decentralized manner. The goal of this course is to familiarize students with basic concepts, models and languages that shaped recent developments in distributed computing. The focus is on exploring new ways of thinking about computing and communication that made the development of distributed software systems possible. Competing concepts and design strategies will be examined both from a theoretical and a practical perspective. Prerequisites: CSE 240 and CSE 247.
Credit 3 units. EN: TU

E81 CSE 538T Modeling and Performance Evaluation of Interconnected Computer Systems

Modern computing systems consist of multiple interconnected components, which all influence performance. The focus of this course is on developing modeling tools aimed at understanding how to design and provision such systems to meet certain performance or efficiency targets, and the trade-offs involved. The course covers Markov chains and their applications to simple queues, and proceeds to explore more complex systems including server farms and how to optimize their performance through scheduling and task assignment policies. The course includes a brief review of the necessary probability and mathematical concepts. Prerequisite: ESE 326.
Credit 3 units. EN: TU

E81 CSE 539S Concepts in Multicore Computing

Nowadays, the vast majority of computer systems are built using multicore processor chips. This fundamental shift in hardware design impacts all areas of computer science — one must write parallel programs in order to unlock the computational power provided by modern hardware. The goal of this course is to study concepts in multicore computing. We will examine the implications of the multicore hardware design, discuss challenges in writing high performance software, and study emerging technologies relevant to developing software for multicore systems. Topics include memory hierarchy, cache coherence protocol, memory models, scheduling, high-level parallel language models, concurrent programming (synchronization and concurrent data structures), algorithms for debugging parallel software, and performance analysis. Prerequisites: CSE 332S and CSE 361S. Credit 3 units. EN: TU

E81 CSE 541T Advanced Algorithms

Provides a broad coverage of fundamental algorithm design techniques with the focus on developing efficient algorithms for solving combinatorial and optimization problems. The topics covered include: greedy algorithms, dynamic programming, linear programming, NP-completeness, approximation algorithms, lower bound techniques, and online algorithms. Throughout this course there is an emphasis on correctness proofs and the ability to apply the techniques taught to design efficient algorithms for problems from a wide variety of application areas. Prerequisites: CSE 347. Credit 3 units. EN: TU

E81 CSE 542T Advanced Data Structures and Algorithms

This course is concerned with the design and analysis of efficient algorithms, focusing principally on algorithms for combinatorial optimization problems. A key element in the course is the role of data structures in algorithm design and the use of amortized complexity analysis to determine how data structures affect performance. The course is organized around a set of core problems and algorithms, including the classical network optimization algorithms, as well as newer and more efficient algorithms. This core is supplemented by algorithms selected from the recent technical literature. Prerequisite: CSE 247. Credit 3 units.

E81 CSE 543S Advanced Secure Software Engineering

The aim of this course is to provide students with broader and deeper knowledge as well as hands-on experience in understanding security techniques and methods needed in software development. Students complete an independent research project which will involve synthesizing multiple software security techniques and applying them to an actual software program or system. Credit 3 units. EN: TU

E81 CSE 543T Algorithms for Nonlinear Optimization

The course will provide an in-depth coverage of modern algorithms for the numerical solution of multidimensional optimization problems. Unconstrained optimization techniques including Gradient methods, Newton's methods, Quasi-Newton methods, and conjugate methods will be introduced. The emphasis is on constrained optimization techniques: Lagrange theory, Lagrangian methods, penalty methods, sequential quadratic programming, primal-dual methods, duality theory,

nondifferentiable dual methods, and decomposition methods. The course will also discuss applications in engineering systems and use of state-of-the-art computer codes. Special topics may include large-scale systems, parallel optimization, and convex optimization. Prerequisites: Calculus I and Math 309. Credit 3 units.

E81 CSE 544T Special Topics in Computer Science Theory

The material for this course varies among offerings, but this course generally covers advanced or specialized topics in computer science theory. A description for a given semester's offering will appear in that semester's course guide. Credit 3 units. EN: TU

E81 CSE 546T Computational Geometry

Computational geometry is the algorithmic study of problems that involve geometric shapes such as points, lines and polygons. Such problems appear in computer graphics, vision, robotics, animation, visualization, molecular biology, and geographic information systems. This course covers data structures that are unique to geometric computing, such as convex hull, Voronoi diagram, Delaunay triangulation, arrangement, range searching, KD-trees, and segment trees. Also covered are algorithms for polygon triangulation, shortest paths, the post office problem, and the art gallery problem. Prerequisite: CSE 247. Credit 3 units.

E81 CSE 547T Introduction to Formal Languages and Automata

An introduction to the theory of computation, with emphasis on the relationship between formal models of computation and the computational problems solvable by those models. Specifically, this course covers finite automata and regular languages; Turing machines and computability; and basic measures of computational complexity and the corresponding complexity classes. Prerequisites: CSE 240 and CSE 247. Credit 3 units.

E81 CSE 548T Concurrent Systems: Design and Verification

Formerly CSE 563T. Concurrency presents programmers with unprecedented complexity further exacerbated by our limited ability to reason about concurrent computations. Yet, concurrent algorithms are central to the development of software executing on modern multiprocessors or across computer networks. This course reviews several important classes of concurrent algorithms and presents a formal method for specifying, reasoning about, verifying, and deriving concurrent algorithms. The selected algorithms are judged to have made significant contributions to our understanding of concurrency. Rigorous treatment of the design and programming process is emphasized. Students entering this course must be familiar with predicate calculus and sequential algorithms. Upon completion of this course students will be able to reason completely formally about small concurrent programs and to apply systematically and correctly their formal skills to larger problems. Prerequisite: CSE 247. Credit 3 units.

E81 CSE 549T Theory of Parallel Systems

The course covers various aspects of parallel programming such as algorithms, schedulers and systems from a theoretical perspective. We will cover both classic and recent results in parallel computing. Topics include parallel algorithms and

analysis in the work/span model, scheduling algorithms, external memory algorithms and their analysis, cache-coherence protocols, etc. The focus will be on design and analysis.

Prerequisite: CSE 247.

Credit 3 units. EN: TU

E81 CSE 552A Advanced Computer Graphics

This course covers advanced topics in graphics in the areas of modeling, rendering, volume rendering, image-based rendering and image processing. Topics include, but are not limited to, subdivision surfaces, splines, mesh simplification, implicit or blobby modeling, radiosity, procedural textures, filtering, BRDFs and procedural modeling. The class has several structured programming assignments and an optional final group project. Students are exposed to the wide variety of techniques available in graphics and also pick one area to study in depth.

Prerequisites: CSE 332S and CSE 452A.

Credit 3 units. EN: TU

E81 CSE 554A Geometric Computing for Biomedicine

With the advance of imaging technologies deployed in medicine, engineering and science, there is a rapidly increasing amount of spatial data sets (images, volumes, point clouds, etc.) that need to be processed, visualized, and analyzed. This course will focus on a number of geometry-related computing problems that are essential in the knowledge discovery process in various spatial-data-driven biomedical applications. These problems include visualization, segmentation, mesh construction and processing, shape representation and analysis. The course consists of lectures that cover theories and algorithms, and a series of hands-on programming projects using real-world data collected by various imaging techniques (CT, MRI, electron cryo-microscopy, etc.). Prerequisites: CSE 247 and CSE 332.

Credit 3 units. EN: TU

E81 CSE 555A Computational Photography

Computational Photography describes the convergence of computer graphics, computer vision, and the internet with photography. Its goal is to overcome the limitations of traditional photography using computational techniques to enhance the way we capture, manipulate and interact with visual media. In this course we study many interesting, recent image-based algorithms and implement them to the degree that is possible. Topics may include: cameras and image formation, human visual perception, image processing (filtering, pyramids), image blending and compositing, image retargeting, texture synthesis and transfer, image completion/inpainting, super-resolution, deblurring, denoising, image-based lighting and rendering, high dynamic range, depth and defocus, flash/no flash photography, coded aperture photography, single/multiview reconstruction, photo quality assessment, non photorealistic rendering, modeling and synthesis using internet data, and others. Prerequisites: CSE 452A, CSE 554A, or CSE 559A.

Credit 3 units. EN: TU

E81 CSE 556A Human-Computer Interaction Methods

An introduction to user centered design processes. The course covers a variety of HCI techniques for use at different stages in the software development cycle, including techniques that can be used with and without users. Students will gain experience using these techniques through in-class exercises and then apply them in greater depth through a semester long interface development project. Students who enroll in this course are expected to be comfortable with building user interfaces

in at least one framework and be willing to learn whatever framework is most appropriate for their project. Over the course of the semester, students will be expected to present their interface evaluation results through written reports and in class presentations. Prerequisites: 3xxS or 4xxS.

Credit 3 units. EN: TU

E81 CSE 557A Information Visualization

We are in an era where it is possible to have all of the world's information at our fingertips. However, the more information we can access, the more difficult it is to obtain a holistic view of the data or to determine what's important to make decisions. Computer-based visualization systems provide the opportunity to represent large and/or complex data visually to aid comprehension and cognition. In this course, we study the principles for transforming abstract data into effective information visualizations. We learn about the state-of-the-art in visualization research and development, and we gain hands-on experience with designing and developing information visualizations. We also learn how to critique existing visualizations and how to evaluate the systems we build. Readings will include current research papers from the Information Visualization community.

Prerequisites: CSE 247 and CSE 330S.

Credit 3 units. EN: TU

E81 CSE 558A Motion Planning

This course studies the general motion planning problem: computing a sequence of motions that transforms a given (initial) arrangement of physical objects to another (goal) arrangement of those objects. Many motion planning methods were developed in the realm of robotics research. For example, a typical problem might be to find a sequence of motions (called a path) to move a robot from one position to another without colliding with any objects in its workspace. However, the general motion planning problem that will be studied arises in many other application domains as well. For example, assembly planning (e.g., finding a valid order for adding the parts when building an engine), mechanical CAD studies (e.g., can you remove a certain part from an engine without taking the engine apart), artificial life simulations (e.g., moving a herd of animals from one location to another), and medicine (e.g., can a drug molecule reach a protein molecule). Prerequisite: CSE 247.

Credit 3 units. EN: TU

E81 CSE 559A Computer Vision

This course introduces the fundamentals of designing computer vision systems: that can "look at" images and videos and reason about the physical objects and scenes they represent. Topics include image restoration and enhancement; estimation of color, shape, geometry, and motion from images; and image segmentation, recognition, and classification. The focus of the course will be on the mathematical tools and intuition underlying algorithms for these tasks: models for the physics and geometry of image formation, and statistical and machine learning-based techniques for inference. Prerequisites: Math 309 and CSE 247.

Credit 3 units. EN: TU

E81 CSE 560M Computer Systems Architecture I

An exploration of the central issues in computer architecture: instruction set design, addressing and register set design, control unit design, microprogramming, memory hierarchies (cache and main memories, mass storage, virtual memory), pipelining, and bus organization. The course emphasizes understanding the performance implications of design choices, using architecture

modeling and evaluation using VHDL and/or instruction set simulation. Prerequisites: CSE 361S and CSE 260M.
Credit 3 units. EN: TU

E81 CSE 561M Computer Systems Architecture II

Advanced techniques in computer system design. Selected topics from: processor design (multithreading, VLIW, data flow, chip-multiprocessors, application specific processors, vector units, large MIMD machines), memory systems (topics in locality, prefetching, reconfigurable and special-purpose memories), system specification and validation, and interconnection networks. Prerequisites: CSE 560M.
Credit 3 units. EN: TU

E81 CSE 564M Advanced Digital Systems Engineering

This course focuses on advance sensor design. The class covers various basic analog and digital building blocks that are common in most sensor integrated circuits. The class extensively uses state-of-the-art CAD program Cadence to simulate and analyze various circuit blocks. The first half of the course focuses on analyzing various operational amplifiers, analog filters, analog memory and analog to digital converters. The second half of the course focuses on understanding the basic building blocks of imaging sensors. The class has a final project consisting of designing a smart sensor using Cadence tools. Prerequisites: ESE 232 and CSE 362M.
Credit 3 units. EN: TU

E81 CSE 565M Acceleration of Algorithms in Reconfigurable Logic

Reconfigurable logic, in the form of Field-Programmable Gate Arrays (FPGAs), enables the deployment of custom hardware for individual applications. To exploit this capability, the application developer is required to specify the design at the register-transfer level. This course explores techniques for designing algorithms that are amenable to hardware acceleration as well as provides experience in actual implementation. Example applications are drawn from a variety of fields, such as networking, computational biology, etc. Prerequisites: basic digital logic (CSE 260M) and some experience with a hardware description language (e.g., VHDL or Verilog).
Credit 3 units. EN: TU

E81 CSE 566S High Performance Computer Systems

Many applications make substantial performance demands upon the computer systems upon which those applications are deployed. In this context, performance is frequently multidimensional, including resource efficiency, power, execution speed (which can be quantified via elapsed run time, data throughput, or latency), etc. Modern computing platforms exploit parallelism and architectural diversity (e.g., co-processors such as graphics engines and/or reconfigurable logic) to achieve the desired performance goals. This course addresses the practical aspects of achieving high performance on modern computing platforms. This includes questions ranging from how the computing platform is designed to how are applications and algorithms expressed to exploit the platform's properties. Particular attention is given to the role of application development tools. Prerequisite: familiarity with software development in Linux preferred, graduate standing or permission of instructor.
Credit 3 units. EN: TU

E81 CSE 567M Computer Systems Analysis

A comprehensive course on performance analysis techniques. The topics include common mistakes, selection of techniques and metrics, summarizing measured data, comparing systems using random data, simple linear regression models, other regression models, experimental designs, 2**k experimental designs, factorial designs with replication, fractional factorial designs, one factor experiments, two factor full factorial design w/o replications, two factor full factorial designs with replications, general full factorial designs, introduction to queueing theory, analysis of single queues, queueing networks, operational laws, mean-value analysis, time series analysis, heavy tailed distributions, self-similar processes, long-range dependence, random number generation, analysis of simulation results, and art of data presentation. Prerequisites: CSE 260M.
Credit 3 units. EN: TU

E81 CSE 568M Imaging Sensors

This course will cover topics on digital imaging sensors including basic operations of silicon photodetectors; CCD and CMOS passive and active sensor operation; temporal and spatial noise in CMOS sensors; spatial resolution and MTF; SNR and dynamic range; high dynamic range architectures and application specific imaging sensors such as polarization imaging and fluorescent imaging sensors. Prerequisites: CSE 260M and ESE 232.
Credit 3 units.

E81 CSE 569M Parallel Architectures and Algorithms

A number of contemporary parallel computer architectures are reviewed and compared. The problems of process synchronization and load balancing in parallel systems are studied. Several selected applications problems are investigated and parallel algorithms for their solution are considered. Selected parallel algorithms are implemented in both a shared memory and distributed memory parallel programming environment. Prerequisites: graduate standing and knowledge of the C programming language.
Credit 3 units. EN: TU

E81 CSE 569S Advanced IoT, Real-Time, and Embedded Systems Security

The aim of this course is to provide students with knowledge and hands-on experience in understanding the security techniques and methods needed for IoT, real-time, and embedded systems. Students complete an independent research project which will involve synthesizing multiple security techniques and applying them to an actual IoT, real-time, or embedded system or device.
Credit 3 units. EN: TU

E81 CSE 570S Recent Advances in Networking

This course covers the latest advances in networking. The topics include Networking Trends, Data Center Network Topologies, Data Center Ethernet, Carrier IP, Multi-Protocol Label Switching (MPLS), Carrier Ethernet, Virtual Bridging, LAN Extension and Virtualization using Layer 3 Protocols, Virtual Routing Protocols, Internet of Things (IoT), Datalink Layer and Management Protocols for IoT, Networking Layer Protocols for IoT, 6LoWPAN, RPL, Messaging Protocols for IoT, MQTT, OpenFlow, Software Defined Networking (SDN) Network Function Virtualization (NFV), Big Data, Networking Issues for Big Data, Network Configuration, and Data Modeling, NETCONF, YIN, YANG, BEEP, and UML. Prerequisite: CSE 473S or equivalent.
Credit 3 units. EN: TU

E81 CSE 571S Network Security

A comprehensive treatment of network security. Topics include Security Overview, Classical Encryption Techniques, Block Ciphers and DES, Basic Concepts in Number Theory and Finite Fields, Advanced Encryption Standard (AES), Block Cipher Operations, Pseudo Random Number Generation and Stream Ciphers, Number Theory, Public Key Cryptography, other Public Key Cryptosystems, Cryptographic Hash Functions, Message Authentication Codes, Digital Signatures, Key Management and Distribution, User Authentication Protocols, Network Access Control and Cloud Security, Transport Level Security, Wireless Network Security, Electronic Mail Security, IP Security, Intrusion Detection, and Malicious Software. Prerequisite: CSE 473S.

Credit 3 units. EN: TU

E81 CSE 573S Protocols for Computer Networks

An introduction to the design, performance analysis and implementation of existing and emerging computer network protocols. Protocols include multiple access protocols (e.g., CSMA/CD, token ring), internet, working with the internet protocol (IP), transport protocols (e.g., UDP, TCP), high-speed bulk transfer protocols, and routing protocols (e.g., BGP, OSPF). General topics include error control, flow control, packet switching, mechanisms for reliable, ordered and bounded-time packet delivery, host-network interfacing and protocol implementation models. Substantial programming exercises supplement lecture topics. Prerequisite: CSE 473S or permission of the instructor.

Credit 3 units. EN: TU

E81 CSE 574S Wireless and Mobile Networking

First course in wireless networking providing a comprehensive treatment of wireless data and telecommunication networks. Topics include recent trends in wireless and mobile networking, wireless coding and modulation, wireless signal propagation, IEEE 802.11a/b/g/n/ac wireless local area networks, 60 GHz millimeter wave gigabit wireless networks, vehicular wireless networks, white spaces, IEEE 802.22 regional area networks, Bluetooth and Bluetooth Smart, wireless personal area networks, wireless protocols for Internet of Things, ZigBee, cellular networks: 1G/2G/3G, LTE, LTE-Advanced, and 5G. Prerequisites: CSE 473S or permission of the instructor.

Credit 3 units. EN: TU

E81 CSE 577M Design and Analysis of Switching Systems

Switching is a core technology in a wide variety of communication networks, including the internet, circuit-switched telephone networks and optical fiber transmission networks. The last decade has been a time of rapid development for switching technology in the internet. Backbone routers with 10 Gb/s links and aggregate capacities of hundreds of gigabits per second are becoming common, and advances in technology are now making multi-terabit routers practical. This course is concerned with the design of practical switching systems and evaluation of their performance and complexity. Prerequisites: CSE 473S and ESE 326.

Credit 3 units. EN: TU

E81 CSE 581T Approximation Algorithms

Numerous optimization problems are intractable to solve optimally. The intractability of a problem could come from the problem's computational complexity, for instance the problem is NP-Hard, or other computational barriers. To cope with the

inability to find an optimal algorithm, one may desire an algorithm that is guaranteed to return a solution that is comparable to the optimum. Such an algorithm is known as an approximation algorithm. Approximation algorithms are a robust way to cope with intractability, and they are widely used in practice or are used to guide the development of practical heuristics. The area of approximation algorithms has developed a vast theory, revealing the underlying structure of problems as well as their different levels of difficulty. The majority of this course will focus on fundamental results and widely applicable algorithmic and analysis techniques for approximation algorithms. Prerequisite: CSE 347.

Credit 3 units. EN: TU

E81 CSE 582T Complexity Theory

An introduction to the quantitative theory of computation with limited resources. The course examines the relative power of limited amounts of basic computational resources, such as time, memory, circuit size, and random bits, as well as parallel, nondeterministic, alternating, and interactive machine models. Models that capture special kinds of computational problems, such as counting problems or approximate solutions, will also be introduced and related to the standard models. This examination will emphasize surprising relationships between seemingly disparate resources and kinds of computational problems. The course will also discuss some meta-theory, illuminating the weaknesses of standard mathematical techniques of the field against its notorious open conjectures. Prerequisites: CSE 347.

Credit 3 units. EN: TU

E81 CSE 583A Topics in Computational Molecular Biology

In-depth discussion of problems and methods in computational molecular biology. Each year three topics will be covered and those will change yearly. Prerequisite: Biol 5495 or instructor's consent.

Same as L41 Biol 5497

Credit 2 units.

E81 CSE 584A Algorithms for Biosequence Comparison

This course surveys algorithms for comparing and organizing discrete sequential data, especially nucleic acid and protein sequences. Emphasis is on tools to support search in massive biosequence databases and to perform fundamental comparison tasks such as DNA short-read alignment. These techniques are also of interest for more general string processing and for building and mining textual databases. Algorithms are presented rigorously, including proofs of correctness and running time where feasible. Topics include classical string matching, suffix array string indices, space-efficient string indices, rapid inexact matching by filtering (including BLAST and related tools), and multiple alignment. Students complete written assignments and implement advanced comparison algorithms to address problems in bioinformatics. This course does not require a biology background. Prerequisites: CSE 347.

Credit 3 units. EN: TU

E81 CSE 585T Sparse Modeling for Imaging and Vision

Sparse modeling is at the heart of modern imaging, vision, and machine learning. It is a fascinating new area of research that seeks to develop highly effective data models. The core idea in sparse modeling theory is a novel redundant transform, where the number of transform coefficients is larger compared to the original data dimension. Together with redundancy comes an opportunity of seeking the sparsest possible representation,

or the one with the fewest non-zeros. This core idea leads to a series of beautiful theoretical and practical results with many applications such as regression, prediction, restoration, extrapolation, compression, detection, and recognition. In this course, we will explore sparse modeling by covering theoretical as well as algorithmic aspects with applications in computational imaging and computer vision. Prerequisites: ESE 318, Math 233, Math 309, and Math 429, or equivalents. Coding with MATLAB or Python.

Credit 3 units. EN: TU

E81 CSE 587A Algorithms for Computational Biology

This course is a survey of algorithms and mathematical methods in biological sequence analysis (with a strong emphasis on probabilistic methods) and systems biology. Sequence analysis topics include introduction to probability, probabilistic inference in missing data problems, hidden Markov models (HMMs), profile HMMs, sequence alignment, and identification of transcription-factor binding sites. Systems biology topics include discovery of gene regulatory networks, quantitative modeling of gene regulatory networks, synthetic biology, and (in some years) quantitative modeling of metabolism. Prerequisites: CSE 131. Credit 3 units.

E81 CSE 591 Introduction to Graduate Study in CSE

Introduces students to the different areas of research conducted in the department. Provides an introduction to research skills, including literature review, problem formulation, presentation, and research ethics. Lecture and discussion are supplemented by exercises in the different research areas and in critical reading, idea generation, and proposal writing. Credit 3 units.

E81 CSE 598 Master's Project

Students electing the project option for their master's degree perform their project work under this course. In order to successfully complete this course, students must defend their project before a three-person committee and present a 2-3 page extended abstract. Prerequisite: permission of adviser and submission of a research proposal form. Credit variable, maximum 6 units.

E81 CSE 599 Master's Research

Students electing the thesis option for their master's degree perform their thesis research under this course. In order to successfully complete a master's thesis, students must enroll in 6 units of this course typically over the course of two consecutive semesters, produce a written thesis, and defend the thesis before a three-person committee. Prerequisite: permission of adviser and submission of a research proposal form. Credit variable, maximum 6 units.

E81 CSE 699 Doctoral Research

Credit variable, maximum 9 units.

E81 CSE 7100 Research Seminar on Machine Learning

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are

encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7200 Research Seminar on Robotics and Human-Computer Interaction

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7300 Research Seminar on Software Systems

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7400 Research Seminar on Algorithms and Theory

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7500 Research Seminar on Graphics and Vision

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7600 Research Seminar on Analog Computing

This seminar will focus on classic and recent papers on analog, stochastic and neuromorphic computing. Students will read, present, and discuss journal papers on analog techniques for implementing sensors and processors. Focus will be placed on fundamental advances and challenges of implementing analog processors. No prerequisites.

Credit 1 unit.

E81 CSE 7700 Research Seminar on Networking and Communications

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7800 Research Seminar on Computational Systems Biology

Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.

Credit 1 unit.

E81 CSE 7900 Research Seminar on Parallel Computing

This seminar will focus on classic and recent papers on parallel computing. Students will read, present and discuss papers on parallel models, algorithms and architectures from top conferences and journals. Focus will be placed on fundamental advances and theoretical models and algorithms, rather than on implementation papers. No prerequisites.

Credit 1 unit.

E81 CSE 801 Pedagogy

A student taking this course studies the fundamentals of teaching in the discipline of computer science and computer engineering. A student enrolled in this course staffs some other course taught by our department, serving as its primary instructor or co-instructor. That student receives frequent mentoring and feedback on preparation and delivery. This course is recommended especially for doctoral students who seek a career in computer science and engineering education.

Credit 3 units.

E81 CSE 883 Master's Continuing Student Status

Master of Science in Computer Science

The Master of Science (MS) in Computer Science is directed toward students with a computer science background who are looking for a program and courses that are more software-focused. It can be either a pure course option program, or it can incorporate either a project or a thesis. If a student chooses a degree option that incorporates a research experience, this MS degree may provide a solid stepping stone to future doctoral studies. All students in the MS in Computer Science program

must have previously completed (as documented by their undergraduate transcript), successfully test to place out of, or complete at the start of their program, the following courses: CSE 501N Introduction to Computer Science and CSE 502N Data Structures and Algorithms, or equivalent courses offered at other institutions.

Course Option

This option requires 30 units of graduate credit. Students must also follow the general degree requirements listed below and complete the breadth requirements.

Thesis/Project Option

The thesis or project options require 24 units of graduate credit in addition to 6 units of either thesis or project courses (CSE 599 or CSE 598 respectively). Students pursuing the project option may opt to take 27 units of graduate courses and only 3 units of CSE 598 with adviser approval. Students must also follow the general degree requirements listed below. Thesis students are exempt from the breadth requirements.

General Degree Requirements

- Breadth requirements (required of the course and project options) which include one 500-level Theoretical Computer Science (T) course, one 500-level Software Systems (S) course, and one 500-level Machine and Architecture (M) course.
- 18 of the 30 units must be departmental courses at the 500-level or above.
- With departmental approval, up to 12 units may be taken from outside of the department. Such approval shall be contingent on the credits being suitably technical graduate-level content. To count more than 6 units from outside the CSE department, an appropriate justification for the additional increment shall be provided by the adviser and student. Departmental approval shall be evaluated with increasing stringency for each additional increment.
- Up to 9 units of 400-level courses can count for graduate credit.
- None of the 30 units may be taken as independent study (i.e., CSE 400 or CSE 500).
- Courses with an "N" designation do not count toward the master's degree.
- All courses must be taken for a grade of C- or better.
- As per Engineering School guidelines, students must maintain a GPA of at least 2.70.

Master of Science in Computer Engineering

The Master of Science (MS) in Computer Engineering is best suited for students who are looking to focus more on computer

engineering (hardware) aspects. Like the MS in Computer Science, the MS in Computer Engineering program can be either a pure course option program, or it can incorporate either a project or a thesis. If appropriate research experiences are included in the degree option, this can also lead toward future doctoral studies. All students in the MS in Computer Engineering program must have previously completed (as documented by their undergraduate transcript), successfully test to place out of, or complete at the start of their program, the following courses: CSE 501N Introduction to Computer Science and CSE 505N Introduction to Digital Logic and Computer Design, or equivalent courses offered at other institutions.

Course Option

This option requires 30 units of graduate credit. Students must also follow the general degree requirements listed below.

Thesis/Project Option

The thesis or project options require 24 units of graduate credit in addition to 6 units of either thesis or project courses (CSE 599 or CSE 598 respectively). Students pursuing the project option may opt to take 27 units of graduate courses and only 3 units of CSE 598 with adviser approval. Students must also follow the general degree requirements listed below.

General Degree Requirements

- 18 of the 30 units must be from the designated graduate-level Computer Engineering courses. Please visit our MS in Computer Engineering website (<https://cse.wustl.edu/graduate/programs/Pages/ms-in-computer-engineering.aspx>) for a comprehensive list.
- In addition to the non-CSE courses on the list of designated graduate-level Computer Engineering courses, up to 12 additional units may be taken from outside the department. Such approval shall be contingent on the credits being suitably technical graduate-level content. To count more than 6 units from outside the CSE department, an appropriate justification for the additional increment shall be provided by the adviser and student. Departmental approval shall be evaluated with increasing stringency for each additional increment.
- Up to 12 units of 400-level courses can count for graduate credit.
- None of the 30 units may be taken as independent study (i.e., CSE 400 or CSE 500).
- Courses with an "N" designation do not count toward the master's degree.
- All courses must be taken for a grade of C- or better.
- As per Engineering School guidelines, students must maintain a GPA of at least 2.70.

Master of Science in Cybersecurity Engineering

The Master of Science (MS) in Cybersecurity Engineering at Washington University will give students the skills, knowledge and expertise to work in the rapidly growing field of cybersecurity and to design, engineer, and architect cybersecurity technology and systems. Graduates of this program will be equipped with the theoretical and hands-on engineering expertise to solve complex cybersecurity problems affecting diverse enterprises worldwide.

The program includes a set of core foundational courses focusing on operating systems as well as network and systems security. Students pursuing this degree may also choose from more advanced cybersecurity elective courses that will build deeper integrative knowledge of key concepts. Work in the program culminates in either a capstone project or final thesis. The capstone project should focus on a specific set of technical cybersecurity challenges with the objective of designing an implementable solution to those challenges. The thesis option allows students to plan, execute, and report on an individual project that addresses a substantial problem covering both practical and scientific aspects. Students planning to pursue a PhD degree after completing the MS in Cybersecurity degree are particularly encouraged to pick the thesis option.

All students in the MS in Cybersecurity Engineering program must have previously completed (as documented by their undergraduate transcript), successfully test to place out of, or complete at the start of their program, the following courses: CSE 501N Introduction to Computer Science and CSE 502N Data Structures and Algorithms, or equivalent courses offered at other institutions.

Core Courses

Code	Title	Units
CSE 422S	Operating Systems Organization	3
CSE 433S	Secure Software Engineering	3
CSE 469S	Security of the Internet of Things and Embedded System Security	3
CSE 473S	Introduction to Computer Networks	3
CSE 523S	Systems Security	3
Total Units		15

Program Electives

Choose three courses:

Code	Title	Units
CSE 522S	Advanced Operating Systems	3
CSE 543S	Advanced Secure Software Engineering	3

CSE 569S	Advanced IoT, Real-Time, and Embedded Systems Security	3
CSE 571S	Network Security	3
T81 INFO 565	Cybersecurity Analytics	3
T81 INFO 566	Cybersecurity Risk Management	3

Culminating Experience

Choose one of the following:

Code	Title	Units
CSE 598	Master's Project	6
CSE 599	Master's Research	6

(6 units required, typically completed over the course of two semesters)

General Degree Requirements

- Students who have already taken core or elective courses specified by the program can, with departmental approval, substitute other courses that are suitably technical and appropriate to the degree program. Departmental approval will require justification and shall be evaluated with increasing stringency for each additional substitution.
- None of the 30 units may be taken as independent study (i.e., CSE 400 or CSE 500).
- Courses with an "N" designation do not count toward the master's degree.
- All courses must be taken for a grade of C- or better.
- As per Engineering School guidelines, students must maintain a GPA of at least 2.70.

Master of Engineering in Computer Science and Engineering

The Master of Engineering (MEng) in Computer Science and Engineering is specifically designed for students who would like to combine studies in computer science and computer engineering, possibly in conjunction with graduate-level work in another discipline, or for other reasons need a more flexible structure to their master's studies. The MEng offers more flexibility by allowing for approved outside courses (i.e., courses not specifically taken in computer science, such as various business courses) to count toward the degree; in this manner, an MEng student can customize their program, incorporating interdisciplinary components when/if approved by the faculty adviser. Work in the program culminates in a capstone project highlighting each student's ambitions, interests, and accomplishments in the program. MEng students typically move directly into the industry. All students in the MEng program must have previously completed (as documented by their undergraduate transcript), successfully test to place out of, or complete at the start of their program, the following courses:

CSE 501N Introduction to Computer Science and CSE 502N Data Structures and Algorithms, or equivalent courses offered at other institutions.

Degree Requirements

- The MEng requires 30 total units including 24 units of graduate-level course work and 6 units of CSE 598 Master's Project culminating in a successful project defense.
- 12 of the remaining 24 units must be departmental courses at the 400 level or above. Of these 12 units, 9 units must be at the 500 level.
- With departmental approval, up to 12 units may be taken from outside of the department. Such approval shall be contingent on the credits being suitably technical graduate-level content. To count more than 6 units from outside the CSE department, an appropriate justification for the additional increment shall be provided by the adviser and student. Departmental approval shall be evaluated with increasing stringency for each additional increment.
- Up to 15 units of 400-level courses can count for graduate credit.
- None of the 30 units may be taken as independent study (i.e., CSE 400 or CSE 500).
- Courses with an "N" designation do not count toward the master's degree.
- All courses must be taken for a grade of C- or better.
- As per Engineering School guidelines, students must maintain a GPA of at least 2.70.

Certificate in Data Mining and Machine Learning

The Certificate in Data Mining and Machine Learning can be awarded in conjunction with any engineering master's degree. In order to qualify for this certificate, students enrolled in any master's in engineering program will need to meet the requirements listed below in addition to the standard requirements for their master's degree.

Required Courses

Code	Title	Units
CSE 417T	Introduction to Machine Learning	3
CSE 517A	Machine Learning	3
CSE 541T	Advanced Algorithms	3
Total Units		9

Foundations Courses

Choose two courses:

Code	Title	Units
CSE 511A	Introduction to Artificial Intelligence	3
CSE 513T	Theory of Artificial Intelligence and Machine Learning	3
CSE 514A	Data Mining	3
CSE 515T	Bayesian Methods in Machine Learning	3
CSE 519T	Advanced Machine Learning	3
Math 493	Probability	3
Math 494	Mathematical Statistics	3

Applications Courses

Choose one course:

Code	Title	Units
CSE 427S	Cloud Computing with Big Data Applications	3
CSE 516A	Multi-Agent Systems	3
CSE 559A	Computer Vision	3
CSE 584A	Algorithms for Biosequence Comparison	3
CSE 587A	Algorithms for Computational Biology	3

Additional Information

- All courses must be taken for a grade.
- Students with previous courses in machine learning may place out of CSE 417T. These students will be required to complete an additional foundations course for a total of three foundations courses.
- Students who began the certificate prior to FL16 who have successfully completed CSE 517A, independent of CSE 417T, will be required to complete an additional foundations course in place of CSE 417T for a total of three foundations courses. No student will be allowed to take CSE 417T after the successful completion of CSE 517A.
- Any student who began the certificate prior to FL16 may choose to take CSE 441T in place of CSE 541T.

PhD in Computer Science or Computer Engineering

Students can choose to pursue a PhD in Computer Science or Computer Engineering. The requirements vary for each degree. Here are the core requirements:

- Complete 72 units of regular courses (at least 33 units), seminars (at least 3 units), and research credits (at least 24 units), including 9 units of breadth requirements for both the PhD in Computer Science and Computer Engineering degrees.

- Satisfy fundamental teaching requirements by participating in mentored teaching experiences, pedagogical teaching requirements by completing a certain number of qualifying pedagogy workshops, and scholarly communication requirements by participating in the Doctoral Student Research Seminar.
- Pass milestones demonstrating abilities to understand research literature, communicate orally and in writing, and formulate a detailed research plan. These milestones include an oral qualifying examination, a portfolio review for admission to candidacy, and a dissertation proposal defense, culminating in a dissertation defense.

For more information, please refer to the Doctoral Program Guide (<https://cse.wustl.edu/graduate/current-students/Pages/phd-students.aspx>) on our website.

Electrical & Systems Engineering

The Department of Electrical & Systems Engineering offers doctoral-level and master's-level degrees in Electrical Engineering and in Systems Science & Mathematics. At the doctoral level, both the PhD and DSc degrees are available, which typically require four to five years of full-time study leading to an original research contribution. At the master's level, the programs require 30 credit hours of study and have both a course option and a thesis option.

Research activity in the department is focused in the following four areas:

Applied Physics

- Nanophotonics
- Quantum optics
- Engineered materials
- Electrodynamics

Devices & Circuits

- Computer engineering
- Integrated circuits
- Radiofrequency circuits
- Sensors

Systems Science

- Optimization
- Applied mathematics
- Control
- Financial engineering

Signals & Imaging

- Computational imaging
- Signal processing

- Optical imaging
- Data sciences

Students working in any of these areas will enjoy the benefits of programs that balance fundamental theoretical concepts with modern applications. In our department, students find ample opportunities for close interactions with faculty members working on cutting-edge research and technology development.

Prospective PhD students with previous degrees in engineering who are interested in PhD studies and research in mathematics or statistics are encouraged to apply for PhD studies in Mathematics and Statistics. For more details, visit the Graduate Programs in Mathematics and Statistics (<http://wumath.wustl.edu/graduate>) webpage.

Phone: 314-935-5565

Website: <http://ese.wustl.edu>

Faculty

Chair

R. Martin Arthur (<https://engineering.wustl.edu/Profiles/Pages/Martin-Arthur.aspx>)

Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, University of Pennsylvania
Ultrasonic imaging, electrocardiography

Endowed Professors

Arye Nehorai (<https://engineering.wustl.edu/Profiles/Pages/Arye-Nehorai.aspx>)

Eugene and Martha Lohman Professor of Electrical Engineering
PhD, Stanford University
Statistical signal processing, machine learning, imaging, biomedicine

Joseph A. O'Sullivan (<https://engineering.wustl.edu/Profiles/Pages/Joseph-OSullivan.aspx>)

Samuel C. Sachs Professor of Electrical Engineering
Dean, UMSL/WashU Joint Undergraduate Engineering Program
PhD, Notre Dame University
Information theory, statistical signal processing, imaging science with applications in medicine and security, and recognition theory and systems

Lan Yang (<https://engineering.wustl.edu/Profiles/Pages/Lan-Yang.aspx>)

Edward H. & Florence G. Skinner Professor of Engineering
PhD, California Institute of Technology
Nano/micro photonics, ultra high-quality optical microcavities, ultra-low-threshold microlasers, nano/micro fabrication, optical sensing, single nanoparticle detection, photonic molecules, photonic materials

Professors

Shantanu Chakrabartty (<https://ese.wustl.edu/faculty/Pages/default.aspx?bio=101>)

PhD, Johns Hopkins University
New frontiers in unconventional analog computing techniques using silicon and hybrid substrates, fundamental limits of energy efficiency, sensing and resolution by exploiting computational and adaptation primitives inherent in the physics of devices

Hiroaki Mukai (<https://engineering.wustl.edu/Profiles/Pages/Hiro-Mukai.aspx>)

Professor
PhD, University of California, Berkeley
Theory and computational methods for optimization, optimal control, systems theory, electric power system operations, differential games

Heinz Schaettler (<https://engineering.wustl.edu/Profiles/Pages/Heinz-Schaettler.aspx>)

PhD, Rutgers University
Optimal control, nonlinear systems, mathematical models in biomedicine

Associate Professors

Jr-Shin Li (<https://engineering.wustl.edu/Profiles/Pages/Jr-Shin-Li.aspx>)

Das Family Distinguished Career Development Associate Professor
PhD, Harvard University
Mathematical control theory, optimization, quantum control, biomedical applications

Assistant Professors

ShiNung Ching (<https://engineering.wustl.edu/Profiles/Pages/ShiNung-Ching.aspx>)

Das Family Distinguished Career Development Assistant Professor
PhD, University of Michigan
Systems and control in neural medicine, nonlinear and constrained control, physiologic network dynamics, stochastic control

Zachary Feinstein (<https://engineering.wustl.edu/Profiles/Pages/Zachary-Feinstein.aspx>)

PhD, Princeton University
Financial engineering, operations research, variational analysis

Ulugbek Kamilov (<https://ese.wustl.edu/faculty/Pages/default.aspx?bio=120>)

PhD, École Polytechnique Fédérale de Lausanne, Switzerland
Computational imaging, signal processing, biomedical imaging

Matthew D. Lew (<https://engineering.wustl.edu/Profiles/Pages/Matthew-Lew.aspx>)

PhD, Stanford University
Microscopy, biophotonics, computational imaging, nano-optics

Jung-Tsung Shen (<https://engineering.wustl.edu/Profiles/Pages/Jung-Tsung-Shen.aspx>)

Das Family Distinguished Career Development Assistant
Professor

PhD, Massachusetts Institute of Technology

Theoretical and numerical investigations on nanophotonics, optoelectronics, plasmonics, metamaterials

Chuan Wang (<https://ese.wustl.edu/faculty/Pages/default.aspx?bio=123>)

PhD, University of Southern California

Flexible electronics, stretchable electronics, printed electronics, nanomaterials, nanoelectronics, optoelectronics

Shen Zeng (<https://ese.wustl.edu/faculty/Pages/default.aspx?bio=121>)

PhD, University of Stuttgart

Systems and control theory, data-based analysis and control of complex dynamical systems, inverse problems, biomedical applications

Xuan "Silvia" Zhang (<https://engineering.wustl.edu/Profiles/Pages/Xuan-%28Silvia%29-Zhang.aspx>)

PhD, Cornell University

Robotics, cyber-physical systems, hardware security, ubiquitous computing, embedded systems, computer architecture, VLSI, electronic design automation, control optimization, and biomedical devices and instrumentation

Senior Professors

I. Norman Katz

PhD, Massachusetts Institute of Technology

Numerical analysis, differential equations, finite element methods, locational equilibrium problems, algorithms for parallel computations

Paul S. Min

PhD, University of Michigan

Routing and control of telecommunication networks, fault tolerance and reliability, software systems, network management

William F. Pickard

PhD, Harvard University

Biological transport, electrobiology, energy engineering

Daniel L. Rode

PhD, Case Western Reserve University

Optoelectronics and fiber optics, semiconductor materials, light-emitting diodes (LEDs) and lasers, semiconductor processing, electronics

Ervin Y. Rodin

PhD, University of Texas at Austin

Optimization, differential games, artificial intelligence, mathematical modeling

Barbara A. Shrauner

PhD, Harvard University (Radcliffe)

Plasma processing, semiconductor transport, symmetries of nonlinear differential equations

Donald L. Snyder

PhD, Massachusetts Institute of Technology

Communication theory, random process theory, signal processing, biomedical engineering, image processing, radar

Barry E. Spielman

PhD, Syracuse University

High-frequency/high-speed devices, RF & MW integrated circuits, computational electromagnetics

Tzyh Jong Tarn

DSc, Washington University

Quantum mechanical systems, bilinear and nonlinear systems, robotics and automation, life science automation

Professors of Practice

Dedric Carter

PhD, Nova Southeastern University

MBA, MIT Sloan School of Management

Dennis Mell

MS, University of Missouri-Rolla

Ed Richter

MS, Washington University

Jason Trobaugh

DSc, Washington University

Senior Lecturer

Martha Hasting

PhD, Saint Louis University

Lecturers

Randall Brown

PhD, Washington University

James Feher

PhD, Missouri University of Science and Technology

Randall Hoven

MS, Johns Hopkins University

Vladimir Kurenok

PhD, Belarus State University (Minsk, Belarus)

Tsitsi Madziwa-Nussinov

PhD, University of California, Los Angeles

Jinsong Zhang

PhD, University of Miami

Professors Emeriti

Lloyd R. Brown

DSc, Washington University
Automatic control, electronic instrumentation

David L. Elliott

PhD, University of California, Los Angeles
Mathematical theory of systems, nonlinear difference, differential equations

Degree Requirements

The Department of Electrical & Systems Engineering offers doctoral-level and master's-level degrees in Electrical Engineering and in Systems Science & Mathematics as well as a certificate in Imaging Science. At the doctoral level, both the PhD and DSc degrees are available, which typically require four to five years of full-time study leading to an original research contribution. At the master's level, the programs require a minimum of 30 credit hours of study consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science. The Master's degrees may be pursued with a course only or thesis option.

Students will enjoy the benefits of programs that balance fundamental theoretical concepts with modern applications. In our department, students find ample opportunities for close interactions with faculty members working on cutting-edge research and technology development.

Please visit the following pages for information about

- Doctoral Degrees (p. 48)
- MS in Electrical Engineering (MSEE) (p. 48)
- MS in Systems Science & Mathematics (MSSSM) (p. 49)
- MS in Data Analytics and Statistics (MSDAS) (p. 50)
- Master of Control Engineering (MCEng) (p. 51)
- Master of Engineering in Robotics (MEngR) (p. 51)
- Certificate in Imaging Science & Engineering (IS&E) (p. 53)

Courses

Visit online course listings to view semester offerings for E35 ESE (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E35&crslvl=5:8>).

E35 ESE 500 Independent Study

Opportunities to acquire experience outside the classroom setting and to work closely with individual members of the faculty. A final report must be submitted to the department. Prerequisite: Students must have the ESE Research/Independent Study Registration Form (PDF) (https://ese.wustl.edu/research/areas/Documents/Independent%20Study%20Form_1.pdf) approved by the department. Credit variable, maximum 3 units.

E35 ESE 501 Mathematics of Modern Engineering I

Matrix algebra: systems of linear equations, vector spaces, linear independence and orthogonality in vector spaces, eigenvectors and eigenvalues; vector calculus: gradient, divergence, curl, line and surface integrals, theorems of Green, Stokes, and Gauss; Elements of Fourier analysis and its applications to solving some classical partial differential equations, heat, wave, and Laplace equation. Prerequisites: ESE 318 and ESE 319 or equivalent or consent of instructor. This course will not count toward the ESE doctoral program.

Credit 3 units. EN: TU

E35 ESE 502 Mathematics of Modern Engineering II

Fourier series and Fourier integral transforms and their applications to solving some partial differential equations, heat and wave equations; complex analysis and its applications to solving real-valued problems: analytic functions and their role, Laurent series representation, complex-valued line integrals and their evaluation including the residual integration theory, conformal mappings and their applications. Prerequisites: ESE 318 and ESE 319 or ESE 317 or equivalent, or consent of instructor. This course will not count toward the ESE doctoral program.

Credit 3 units. EN: TU

E35 ESE 512 Advanced Numerical Analysis

Special topics chosen from numerical solution of partial differential equations, uniform and least-squares approximation spline approximation, Galerkin methods and finite element approximation, functional analysis applied to numerical mathematics, and other topics of interest. Prerequisite: ESE 511 or consent of instructor.

Credit 3 units. EN: TU

E35 ESE 513 Convex Optimization and Duality Theory

Graduate introduction to convex optimization with emphasis on convex analysis and duality theory. Topics include: convex sets, convex functions, convex cones, convex conjugates, Fenchel-Moreau theorem, convex duality and biconjugation, directional derivatives, subgradients and subdifferentials, optimality conditions, ordered vector spaces, Hahn-Banach theorem, extension and separation theorems, minimax theorems, and vector and set optimization. Prerequisites: ESE 415, Math 4111. Credit 3 units.

E35 ESE 514 Calculus of Variations

Introduction to the theory and applications of the calculus of variations. Theory of functionals; variational problems for an unknown function; Euler's equation; variable end-point problems; variational problems with subsidiary conditions; sufficient conditions for extrema: applications to optimum control and/or to other fields. A term project is required. Prerequisites: ESE 318 and 319 or ESE 317 or equivalent.

Credit 3 units.

E35 ESE 515 Nonlinear Optimization

Nonlinear optimization problems with and without constraints and computational methods for solving them. Optimality conditions, Kuhn-Tucker conditions, Lagrange duality; gradient and Newton's methods; conjugate direction and quasi-Newton methods; primal and penalty methods; Lagrange methods. Use of MATLAB optimization techniques in numerical problems.

Prerequisites: CSE 131, Math 309 and ESE 318 or permission of instructor.

Credit 3 units. EN: TU

E35 ESE 516 Optimization in Function Space

Linear vector spaces, normed linear spaces, Lebesgue integrals, the L_p spaces, linear operators, dual space, Hilbert spaces. Projection theorem, Hahn-Banach theorem. Hyperplanes and convex sets, Gateaux and Fréchet differentials, unconstrained minima, adjoint operators, inverse function theorem. Constrained minima, equality constraints, Lagrange multipliers, calculus of variations, Euler-Lagrange equations, positive cones, inequality constraints. Kuhn-Tucker theorem, optimal control theory, Pontryagin's maximum principle, successive approximation methods, Newton's methods, steepest descent methods, primal-dual methods, penalty function methods, multiplier methods. Prerequisite: Math 4111.

Credit 3 units.

E35 ESE 517 Partial Differential Equations

Linear and nonlinear first order equations. Characteristics. Classification of equations. Theory of the potential linear and nonlinear diffusion theory. Linear and nonlinear wave equations. Initial and boundary value problems. Transform methods. Integral equations in boundary value problems. Prerequisites: ESE 318 and 319 or equivalent or consent of instructor.

Credit 3 units. EN: TU

E35 ESE 518 Optimization Methods in Control

The course is divided in two parts: convex optimization and optimal control. In the first part we cover applications of Linear Matrix Inequalities and Semi-Definite Programming to control and estimation problems. We also cover Multiparametric Linear Programming and its application to the Model Predictive Control and Estimation of linear systems. In the second part we cover numerical methods to solve optimal control and estimation problems. We cover techniques to discretize optimal control problems, numerical methods to solve them, and their optimality conditions. We apply these results to the Model Predictive Control and Estimation of nonlinear systems. Prerequisites: ESE 551, and ESE 415 or equivalent.

Credit 3 units. EN: TU

E35 ESE 519 Convex Optimization

Concentrates on recognizing and solving convex optimization problems that arise in applications. Convex sets, functions, and optimization problems. Basics of convex analysis. Least-squares, linear and quadratic programs, semidefinite programming, minimax, extremal volume, and other problems. Optimality conditions, duality theory, theorems of alternative, and applications. Interior-point methods. Applications to signal processing, statistics and machine learning, control and mechanical engineering, digital and analog circuit design, and finance. Prerequisites: Math 309 and ESE 415.

Credit 3 units.

E35 ESE 520 Probability and Stochastic Processes

Review of probability theory; models for random signals and noise; calculus of random processes; noise in linear and nonlinear systems; representation of random signals by sampling and orthonormal expansions. Poisson, Gaussian and Markov processes as models for engineering problems. Prerequisite: ESE 326.

Credit 3 units. EN: TU

E35 ESE 521 Random Variables and Stochastic Processes I

Mathematical foundations of probability theory, including constructions of measures, Lebesgue-measure, Lebesgue-integral, Banach space property of L_p , basic Hilbert-space theory, conditional expectation. Kolmogorov's theorems on existence and sample-path continuity of stochastic processes. An in-depth look at the Wiener process. Filtrations and stopping times. Markov processes and diffusions, including semigroup properties and the Kolmogorov forward and backward equations. Prerequisites: ESE 520 or equivalent, Math 411.

Credit 3 units.

E35 ESE 523 Information Theory

Discrete source and channel model, definition of information rate and channel capacity, coding theorems for sources and channels, encoding and decoding of data for transmission over noisy channels. Corequisite: ESE 520.

Credit 3 units. EN: TU

E35 ESE 524 Detection and Estimation Theory

Study of detection and estimation of signals in noise. Linear algebra, vector spaces, independence, projections. Data independence, factorization theorem and sufficient statistics. Neyman-Pearson and Bayes detection. Least squares, maximum-likelihood and maximum a posteriori estimation of signal parameters. Conjugate priors, recursive estimation, Wiener and Kalman filters. Prerequisite: ESE 520.

Credit 3 units. EN: TU

E35 ESE 526 Network Science

This course focuses on fundamental theory, modeling, structure, and analysis methods in network science. The first part of the course includes basic network models and their mathematical principles. Topics include a review of graph theory, random graph models, scale-free network models and dynamic networks. The second part of the course includes structure and analysis methods in network science. Topics include network robustness, community structure, spreading phenomena and clique topology. Applications of the topics covered by this course include social networks, power grid, internet, communications, protein-protein interactions, epidemic control, global trade, neuroscience, etc. Prerequisite courses: ESE 520 (Probability and Stochastic Processes), Math 429 (Linear Algebra) or equivalent.

Credit 3 units.

E35 ESE 529 Special Topics in Information Theory and Applied Probability

Credit 3 units.

E35 ESE 531 Nano and Micro Photonics

This course focuses on fundamental theory, design, and applications of photonic materials and micro/nano photonic devices. It includes review and discussion of light-matter interactions in nano and micro scales, propagation of light in waveguides, nonlinear optical effect and optical properties of nano/micro structures, the device principles of waveguides, filters, photodetectors, modulators and lasers. Prerequisite: ESE 330.

Credit 3 units. EN: TU

E35 ESE 532 Introduction to Nano-Photonic Devices

Introduction to photon transport in nano-photonic devices. This course focuses on the following topics: light and photons, statistical properties of photon sources, temporal and spatial correlations, light-matter interactions, optical nonlinearity, atoms and quantum dots, single- and two-photon devices, optical devices, and applications of nano-photonic devices in quantum and classical computing and communication. Prerequisites: ESE 330 and Physics 217, or permission of instructor. Credit 3 units. EN: TU

E35 ESE 534 Special Topics in Advanced Electrodynamics

This course covers advanced topics in electrodynamics. Topics include electromagnetic wave propagation (in free space, confined waveguides, or along engineered surfaces); electromagnetic wave scattering (off nano-particles or molecules); electromagnetic wave generation and detection (antenna and nano-antenna); inverse scattering problems; and numerical and approximate methods. Prerequisites: ESE 330, or Physics 421 and Physics 422. Credit 3 units. EN: TU

E35 ESE 536 Introduction to Quantum Optics

This course covers the following topics: quantum mechanics for quantum optics, radiative transitions in atoms, lasers, photon statistics (photon counting, Sub-/Super-Poissonian photon statistics, bunching, anti-bunching, theory of photodetection, shot noise), entanglement, squeezed light, atom-photon interactions, cold atoms, atoms in cavities. If time permits, the following topics are selectively covered: quantum computing, quantum cryptography, and teleportation. Prerequisites: ESE 330 and Physics 217 or Physics 421. Credit 3 units. EN: TU

E35 ESE 538 Advanced Electromagnetic Engineering

The course builds on undergraduate electromagnetics to systematically develop advanced concepts in electromagnetic theory for engineering applications. The following topics are covered: Maxwell's equations; fields and waves in materials; electromagnetic potentials and topics for circuits and systems; transmission-line essentials for digital electronics and for communications; guided wave principles for electronics and optoelectronics; principles of radiation and antennas; and numerical methods for computational electromagnetics. Credit 3 units.

E35 ESE 543 Control Systems Design by State Space Methods

Advanced design and analysis of control systems by state-space methods: classical control review, Laplace transforms, review of linear algebra (vector space, change of basis, diagonal and Jordan forms), linear dynamic systems (modes, stability, controllability, state feedback, observability, observers, canonical forms, output feedback, separation principle and decoupling), nonlinear dynamic systems (stability, Lyapunov methods). Frequency domain analysis of multivariable control systems. State space control system design methods: state feedback, observer feedback, pole placement, linear optimal control. Design exercises with CAD (computer-aided design) packages for engineering problems. Prerequisite: ESE 351 and ESE 441, or permission of instructor. Credit 3 units. EN: TU

E35 ESE 544 Optimization and Optimal Control

Constrained and unconstrained optimization theory. Continuous time as well as discrete-time optimal control theory. Time-optimal control, bang-bang controls and the structure of the reachable set for linear problems. Dynamic programming, the Pontryagin maximum principle, the Hamiltonian-Jacobi-Bellman equation and the Riccati partial differential equation. Existence of classical and viscosity solutions. Application to time optimal control, regulator problems, calculus of variations, optimal filtering and specific problems of engineering interest. Prerequisites: ESE 551, ESE 552. Credit 3 units. EN: TU

E35 ESE 545 Stochastic Control

Introduction to the theory of stochastic differential equations based on Wiener processes and Poisson counters, and an introduction to random fields. The formulation and solution of problems in nonlinear estimation theory. The Kalman-Bucy filter and nonlinear analogues. Identification theory. Adaptive systems. Applications. Prerequisites: ESE 520 and ESE 551. Credit 3 units. EN: TU

E35 ESE 546 Dynamics & Control in Neuroscience & Brain Medicine

This course provides an introduction to systems engineering approaches to modeling, analysis and control of neuronal dynamics at multiple scales. A central motivation is the manipulation of neuronal activity for both scientific and medical applications using emerging neurotechnology and pharmacology. Emphasis is placed on dynamical systems and control theory, including bifurcation and stability analysis of single neuron models and population mean-field models. Synchronization properties of neuronal networks are covered and methods for control of neuronal activity in both oscillatory and non-oscillatory dynamical regimes are developed. Statistical models for neuronal activity are also discussed. An overview of signal processing and data analysis methods for neuronal recording modalities is provided, toward the development of closed-loop neuronal control paradigms. The final evaluation is based on a project or research survey. Prerequisite(s): ESE 553 (or equivalent); ESE 520 (or equivalent); ESE 351 (or equivalent). Credit 3 units. EN: TU

E35 ESE 547 Robust and Adaptive Control

Graduate-level control system design methods for multi-input multi-output systems. Linear optimal-based methods in robust control, nonlinear model reference adaptive control. These design methods are currently used in most industry control system design problems. These methods are designed, analyzed and simulated using MATLAB. Linear control theory (review), robustness theory (Mu Analysis), optimal control and the robust servomechanism, H-infinity optimal control, robust output feedback controls, Kalman filter theory and design, linear quadratic gaussian with loop transfer recovery, the Loop Transfer Recovery method of Lavretsky, Mu synthesis, Lyapunov theory (review), LaSalle extensions, Barbalat's Lemma, model reference adaptive control, artificial neural networks, online parameter estimation, convergence and persistence of excitation. Prerequisite: ESE 543 or ESE 551 or equivalent. Credit 3 units. EN: TU

E35 ESE 549 Special Topics in Control

Credit 3 units.

E35 ESE 551 Linear Dynamic Systems I

Input-output and state-space description of linear dynamic systems. Solution of the state equations and the transition matrix. Controllability, observability, realizations, pole-assignment, observers and decoupling of linear dynamic systems. Prerequisite: ESE 351.

Credit 3 units. EN: TU

E35 ESE 552 Linear Dynamic Systems II

Least squares optimization problems. Riccati equation, terminal regulator and steady-state regulator. Introduction to filtering and stochastic control. Advanced theory of linear dynamic systems. Geometric approach to the structural synthesis of linear multivariable control systems. Disturbance decoupling, system invertibility and decoupling, extended decoupling and the internal model principle. Prerequisite: ESE 551.

Credit 3 units. EN: TU

E35 ESE 553 Nonlinear Dynamic Systems

State space and functional analysis approaches to nonlinear systems. Questions of existence, uniqueness and stability; Lyapunov and frequency-domain criteria; w -limits and invariance, center manifold theory and applications to stability, steady-state response and singular perturbations. Poincare-Bendixson theory, the van der Pol oscillator, and the Hopf Bifurcation theorem. Prerequisite: ESE 551.

Credit 3 units. EN: TU

E35 ESE 554 Advanced Nonlinear Dynamic Systems

Differentiable manifolds, vector fields, distributions on a manifold, Frobenius' theorem, Lie algebras. Controllability, observability of nonlinear systems, examined from the viewpoint of differential geometry. Transformation to normal forms. Exact linearization via feedback. Zero dynamics and related properties. Noninteracting control and disturbance decoupling. Controlled invariant distributions. Noninteracting control with internal stability. Prerequisites: ESE 553 and ESE 551.

Credit 3 units.

E35 ESE 557 Hybrid Dynamic Systems

Theory and analysis of hybrid dynamic systems, which is the class of systems whose state is composed by continuous-valued and discrete-valued variables. Discrete-event systems models and language descriptions. Models for hybrid systems. Conditions for existence and uniqueness. Stability and verification of hybrid systems. Optimal control of hybrid systems. Applications to cyber-physical systems and robotics. Prerequisite: ESE 551.

Credit 3 units. EN: TU

E35 ESE 559 Special Topics in Systems

Credit 3 units.

E35 ESE 560 Computer Systems Architecture I

An exploration of the central issues in computer architecture: instruction set design, addressing and register set design, control unit design, microprogramming, memory hierarchies (cache and main memories, mass storage, virtual memory), pipelining, and bus organization. The course emphasizes understanding the

performance implications of design choices, using architecture modeling and evaluation using VHDL and/or instruction set simulation. Prerequisites: CSE 361S and CSE 260M.

Same as E81 CSE 560M

Credit 3 units. EN: TU

E35 ESE 562 Analog Integrated Circuits

This course focuses on fundamental and advanced topics in analog and mixed-signal VLSI techniques. The first part of the course covers graduate-level materials in the area of analog circuit synthesis and analysis. The second part of the course covers applications of the fundamental techniques for designing analog signal processors and data converters. Several practical aspects of mixed-signal design, simulation and testing are covered in this course. This is a project-oriented course, and it is expected that the students apply the concepts learned in the course to design, simulate and explore different circuit topologies. Prerequisites: CSE 260 and ESE 232.

Credit 3 units.

E35 ESE 566A Modern System-on-Chip Design

The System-on-Chip (SoCs) technology is at the core of most electronic systems: smart phones, wearable devices, autonomous robots, and cars, aerospace or medical electronics. In these SoCs, billions of transistors can be integrated on a single silicon chip, containing various components such as microprocessors, DSPs, hardware accelerators, memories, and I/O interfaces. Topics include SoC architectures, design tools and methods, as well as system-level tradeoffs between performance, power consumption, energy efficiency, reliability, and programmability. Students will gain an insight into the early stage of the SoC design process performing the tasks of developing functional specification, partition and map functions onto hardware and/or software, and evaluating and validating system performance. Assignments include hands-on design projects. Open to both graduate and senior undergraduate students. Prerequisite: ESE 461.

Credit 3 units. EN: TU

E35 ESE 567 Computer Systems Analysis

A comprehensive course on performance analysis techniques. The topics include common mistakes, selection of techniques and metrics, summarizing measured data, comparing systems using random data, simple linear regression models, other regression models, experimental designs, 2^{**k} experimental designs, factorial designs with replication, fractional factorial designs, one factor experiments, two factor full factorial design w/o replications, two factor full factorial designs with replications, general full factorial designs, introduction to queueing theory, analysis of single queues, queueing networks, operational laws, mean-value analysis, time series analysis, heavy tailed distributions, self-similar processes, long-range dependence, random number generation, analysis of simulation results, and art of data presentation. Prerequisites: CSE 260M.

Same as E81 CSE 567M

Credit 3 units. EN: TU

E35 ESE 569 Parallel Architectures and Algorithms

Several contemporary parallel computer architectures are reviewed and compared. The problems of process synchronization and load balancing in parallel systems are studied. Several selected applications problems are investigated and parallel algorithms for their solution are considered. Selected parallel algorithms are implemented in both a shared memory

and distributed memory parallel programming environment.
Prerequisites: graduate standing and knowledge of the C programming language.
Same as E81 CSE 569M
Credit 3 units. EN: TU

E35 ESE 570 Coding Theory

Introduction to the algebra of finite fields. Linear block codes, cyclic codes, BCH and related codes for error detection and correction. Encoder and decoder circuits and algorithms. Spectral descriptions of codes and decoding algorithms. Code performances.
Credit 3 units. EN: TU

E35 ESE 571 Transmission Systems and Multiplexing

Transmission and multiplexing systems are essential to providing efficient point-to-point communication over distance. This course introduces the principles underlying modern analog and digital transmission and multiplexing systems and covers a variety of system examples.
Credit 3 units. EN: TU

E35 ESE 572 Signaling and Control in Communication Networks

The operation of modern communications networks is highly dependent on sophisticated control mechanisms that direct the flow of information through the network and oversee the allocation of resources to meet the communication demands of end users. This course covers the structure and operation of modern signaling systems and addresses the major design trade-offs that center on the competing demands of performance and service flexibility. Specific topics covered include protocols and algorithms for connection establishment and transformation, routing algorithms, overload and failure recovery and networking dimensioning. Case studies provide concrete examples and reveal the key design issues. Prerequisites: graduate standing and permission of instructor.
Credit 3 units. EN: TU

E35 ESE 575 Fiber-Optic Communications

Introduction to optical communications via glass-fiber media. Pulse-code modulation and digital transmission methods, coding laws, receivers, bit-error rates. Types and properties of optical fibers; attenuation, dispersion, modes, numerical aperture. Light-emitting diodes and semiconductor laser sources; device structure, speed, brightness, modes, electrical properties, optical and spectral characteristics. Prerequisites: ESE 330, ESE 336.
Credit 3 units. EN: TU

E35 ESE 581 Radar Systems

An introduction to the selection and processing of radar signals. Signal design for improving range and Doppler resolution, ambiguity functions, chirp and stepped-frequency waveforms, pulse-compression codes. Statistical models for radar data: range-spread, Doppler-spread, doubly spread reflectors. Matched-filter and estimator-correlator receivers for range and Doppler estimation. Tracking. Multiantenna radar receivers: interference rejection, adaptive canceling. Delay-Doppler radar-imaging using synthetic-aperture processing. Prerequisite: ESE 524.
Credit 3 units. EN: TU

E35 ESE 582 Fundamentals and Applications of Modern Optical Imaging

Analysis, design and application of modern optical imaging systems with emphasis on biological imaging. First part of the course focuses on the physical principles underlying the operation of imaging systems and their mathematical models. Topics include ray optics (speed of light, refractive index, laws of reflection and refraction, plane surfaces, mirrors, lenses, aberrations), wave optics (amplitude and intensity, frequency and wavelength, superposition and interference, interferometry), Fourier optics (space-invariant linear systems, Huygens-Fresnel principle, angular spectrum, Fresnel diffraction, Fraunhofer diffraction, frequency analysis of imaging systems), and light-matter interaction (absorption, scattering, dispersion, fluorescence). Second part of the course compares modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students evaluate and critique recent optical imaging literature. Prerequisites: ESE 318 and ESE 319 or their equivalents; ESE 330 or Physics 421 or equivalent.
Credit 3 units. EN: TU

E35 ESE 584 Statistical Signal Processing for Sensor Arrays

Methods for signal processing and statistical inference for data acquired by an array of sensors, such as those found in radar, sonar and wireless communications systems. Multivariate statistical theory with emphasis on the complex multivariate normal distribution. Signal estimation and detection in noise with known statistics, signal estimation and detection in noise with unknown statistics, direction finding, spatial spectrum estimation, beam forming, parametric maximum-likelihood techniques. Subspace techniques, including MUSIC and ESPRIT. Performance analysis of various algorithms. Advanced topics may include structured covariance estimation, wide-band array processing, array calibration, array processing with polarization diversity, and space-time adaptive processing (STAP). Prerequisites: ESE 520, ESE 524, linear algebra, computer programming.
Credit 3 units. EN: TU

E35 ESE 588 Quantitative Image Processing

Introduction to modeling, processing, manipulation and display of images. Application of two-dimensional linear systems to image processing. Two-dimensional sampling and transform methods. The eye and perception. Image restoration and reconstruction. Multiresolution processing, noise reduction and compression. Boundary detection and image segmentation. Case studies in image processing (examples: computer tomography and ultrasonic imaging). Prerequisites: ESE 326, ESE 482.
Credit 3 units. EN: TU

E35 ESE 589 Biological Imaging Technology

This class develops a fundamental understanding of the physics and mathematical methods that underlie biological imaging and critically examine case studies of seminal biological imaging technology literature. The physics section examines how electromagnetic and acoustic waves interact with tissues and cells, how waves can be used to image the biological structure and function, image formation methods, and diffraction limited imaging. The math section examines image decomposition using basis functions (e.g., Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multidimensional imaging datasets, multivariate regression, and statistical image analysis. Original literature

on electron, confocal and two photon microscopy, ultrasound, computed tomography, functional and structural magnetic resonance imaging and other emerging imaging technology are critiqued.

Credit 3 units. EN: TU

E35 ESE 590 Electrical & Systems Engineering Graduate Seminar

This pass/fail course is required for the MS, DSc and PhD degrees in Electrical & Systems Engineering. A passing grade is required for each semester of enrollment and is received by attendance at regularly scheduled ESE seminars. MS students must attend at least three seminars per semester. DSc and PhD students must attend at least five seminars per semester. Part-time students are exempt except during their year of residency. Any student under continuing status is also exempt. Seminars missed in a given semester may be made up during the subsequent semester.

E35 ESE 596 Seminar in Imaging Science and Engineering

This seminar course consists of a series of tutorial lectures on Imaging Science and Engineering with emphasis on applications of imaging technology. Students are exposed to a variety of imaging applications that vary depending on the semester, but may include multispectral remote sensing, astronomical imaging, microscopic imaging, ultrasound imaging and tomographic imaging. Guest lecturers come from several parts of the university. This course is required of all students in the Imaging Science and Engineering program; the only requirement is attendance. This course is graded pass/fail. Prerequisite: admission to Imaging Science and Engineering program. Same as CSE 596 (when offered) and BME 506.
Credit 1 unit.

E35 ESE 599 Master's Research

Prerequisite: Students must have the ESE Research/Independent Study Registration Form (PDF) (https://ese.wustl.edu/research/areas/Documents/Independent%20Study%20Form_1.pdf) approved by the department.
Credit variable, maximum 3 units.

E35 ESE 600 Doctoral Research

Credit variable, maximum 9 units.

E35 ESE 883 Master's Continuing Student Status

Doctoral Degrees

Electrical Engineering or Systems Science & Mathematics

Students pursuing the Doctor of Philosophy (PhD) or Doctor of Science (DSc) degrees in Electrical Engineering or Systems Science & Mathematics must complete a minimum of 72 credit hours of post-baccalaureate study consistent with the residency and other applicable requirements of Washington University in St. Louis and the Graduate School. These 72 units must consist of at least 36 units of course work and at least 24 units of research, and may include work done to satisfy the requirements

of a master's degree in a related discipline. Up to 24 units for the PhD and 30 units for the DSc may be transferred to Washington University in St. Louis from another institution.

Following are stages to the completion of the requirements for a doctoral degree in the Department of Electrical & Systems Engineering. Each candidate for the degree must:

- Complete at least 36 hours of post-baccalaureate course work
- Pass a written qualifying examination, to be taken before the second academic year of the program
- Pass an oral preliminary research examination, to be completed within two years of passing the written qualifying examination, and at least one year prior to completion of the dissertation
- Satisfy the general residency requirement for the Graduate School (PhD) or the School of Engineering & Applied Science (DSc)
- Satisfy the general teaching requirement for PhD degrees offered by the Graduate School; no teaching requirement for the DSc
- Write a doctoral dissertation that describes the results of original and creative research in a specialization within electrical engineering or systems science and mathematics
- Pass a final oral examination in defense of the dissertation research
- Take ESE 590 Electrical & Systems Engineering Graduate Seminar each semester

The doctoral degree should ordinarily take no more than five years to complete, for students who enter the program with a baccalaureate degree. While individual circumstances will vary, the typical timeline will be as follows:

- Year 1: Course work and written qualifying examination
- Year 2: Course work, preliminary research, research advisory committee selection
- Year 3: Course work and preliminary research examination
- Year 4: Research
- Year 5: Research, completion of dissertation, and final oral examination

Students who enter the program with a master's degree may be able to shorten this timeline by one year or more.

Master of Science in Electrical Engineering (MSEE)

Master's Degrees

Either a thesis option or a course option may be selected. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under the course option, students may not take ESE 599 Master's Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and 6 credit hours of thesis research (ESE 599). Three (3) of these credit hours of thesis research may be applied toward the 15 core electrical engineering credit hours required for the MSEE program. Any of these 6 hours of thesis research may be applied as electives for the MSEE, MSSSM, MSDAS, MCEng and MEngR programs. The student must write a master's thesis and defend it in an oral examination.

MS in Electrical Engineering

Students pursuing the degree Master of Science in Electrical Engineering (MSEE) must complete a minimum of 30 credit hours of study consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science, and subject to the following departmental requirements.

- A minimum of 15 of these credit hours must be selected from the following list of core electrical engineering subjects taught by the Department of Electrical & Systems Engineering (ESE).
 - ESE 415 Optimization
 - ESE 513 Convex Optimization and Duality Theory
 - ESE 516 Optimization in Function Space
 - ESE 519 Convex Optimization
 - ESE 520-529 Applied probability category
 - ESE 530-539 Applied physics and electronics category
 - ESE 540-549 Control category
 - ESE 550-559 Systems category
 - ESE 560-569 Computer engineering category
 - ESE 570-579 Communications category
 - ESE 580-589 Signal and image processing category
 - ESE 599 Master's Research (thesis option only, max 3 units)
- The remaining courses in the program may be selected from senior- or graduate-level courses in ESE or elsewhere in the university. Courses outside of ESE must be in technical subjects relevant to electrical engineering and require the department's approval. Undergraduate Laboratory courses may not be used to satisfy this requirement.

- At least 15 units of the 30 total units applied toward the MSEE degree must be in ESE courses which, if cross-listed, have ESE as the home department.
- A maximum of 6 credits may be transferred from another institution and applied toward the MSEE degree. Regardless of subject or level, all transfer courses are treated as electives and do not count toward the requirement of 15 credit hours of graduate-level electrical engineering courses.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken each semester. Master of Science students must attend at least three seminars per semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

Master of Science in Systems Science & Mathematics (MSSSM)

Master's Degrees

Either a thesis option or a course option may be selected. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under the course option, students may not take ESE 599 Master's Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and 6 credit hours of thesis research (ESE 599). Three (3) of these credit hours of thesis research may be applied toward the 15 core electrical engineering credit hours required for the MSEE program. Any of these 6 hours of thesis research may be applied as electives for the MSEE, MSSSM, MSDAS, MCEng and MEngR programs. The student must write a master's thesis and defend it in an oral examination.

MS in Systems Science & Mathematics

The Master of Science in Systems Science & Mathematics (MSSSM) is an academic master's degree designed mainly for

both full-time and part-time students interested in proceeding to the departmental full-time doctoral program and/or an industrial career.

- The MS degree requires 30 units, which may include optionally 6 units for thesis or independent study.
- Required courses (15 units) for the MS degree include:

Code	Title	Units
ESE 551	Linear Dynamic Systems I	3
ESE 553	Nonlinear Dynamic Systems	3
ESE 520	Probability and Stochastic Processes	3
ESE 415	Optimization ¹	3
and one chosen from the following courses:		
ESE 524	Detection and Estimation Theory	3
or ESE 544	Optimization and Optimal Control	
or ESE 545	Stochastic Control	
or ESE 557	Hybrid Dynamic Systems	
Total Units		15

¹ ESE 516 may be substituted for ESE 415.

- The remaining courses in the program may be selected from senior- or graduate-level courses in Electrical & Systems Engineering or elsewhere in the university. Courses outside of Electrical & Systems Engineering must be in technical subjects relevant to systems science and mathematics and require the department's approval.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken each semester. Master of Science students must attend at least three seminars per semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

Master of Science in Data Analytics and Statistics (MSDAS)

Master's Degrees

Either a thesis option or a course option may be selected. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under

the course option, students may not take ESE 599 Master's Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and 6 credit hours of thesis research (ESE 599). Three (3) of these credit hours of thesis research may be applied toward the 15 core electrical engineering credit hours required for the MSEE program. Any of these 6 hours of thesis research may be applied as electives for the MSEE, MSSSM, MSDAS, MCEng and MEngR programs. The student must write a master's thesis and defend it in an oral examination.

MS in Data Analytics and Statistics

The MS in Data Analytics and Statistics (MSDAS) is an academic master's degree designed for students interested in learning statistical techniques necessary to make informed decisions based on data analysis.

- The MSDAS degree requires 30 units, which may include optionally 6 units for thesis.
- Required courses (15 units) for the MS degree include:

Code	Title	Units
ESE 520	Probability and Stochastic Processes	3
or Math 493	Probability	
ESE 524	Detection and Estimation Theory	3
Math 494	Mathematical Statistics	3
CSE 514A	Data Mining	3
or CSE 517A	Machine Learning	
or CSE 530S	Database Management Systems	
ESE 415	Optimization	3
or ESE 516	Optimization in Function Space	
or ESE 518	Optimization Methods in Control	
Total Units		15

- The remaining courses in the program may be selected from senior- or graduate-level courses in ESE or elsewhere in the university. Courses must be in technical subjects relevant to statistics, optimization, computation, or applications of data analysis and require the department's approval.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken each semester. Master of Science students must attend at least three seminars per semester.
- A maximum of 6 credits may be transferred from another institution and applied toward the Master of Science degree. Regardless of subject or level, all transfer courses are treated as electives and do not count toward the requirement

of 15 credit hours of graduate-level electrical engineering courses.

- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

Master of Control Engineering (MCEng)

Master's Degrees

Either a thesis option or a course option may be selected. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under the course option, students may not take ESE 599 Master's Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and 6 credit hours of thesis research (ESE 599). Three (3) of these credit hours of thesis research may be applied toward the 15 core electrical engineering credit hours required for the MSEE program. Any of these 6 hours of thesis research may be applied as electives for the MSEE, MSSSM, MSDAS, MCEng and MEngR programs. The student must write a master's thesis and defend it in an oral examination.

Master of Control Engineering

The Master of Control Engineering (MCEng) degree is a terminal professional degree designed for students interested in an industrial career.

- The MCEng degree requires 30 units, which may include optionally 6 units for thesis or independent study.
- Required courses (15 units) for the MCEng degree include:

Code	Title	Units
ESE 441	Control Systems	3
ESE 543	Control Systems Design by State Space Methods	3
ESE 520	Probability and Stochastic Processes	3

and at least two of the following six courses:

- ESE 415 Optimization
- or ESE 425 Random Processes and Kalman Filtering
- or ESE 551 Linear Dynamic Systems I
- or ESE 552 Linear Dynamic Systems II
- or ESE 553 Nonlinear Dynamic Systems
- or ESE 547 Robust and Adaptive Control

- Elective Courses (15 units): The 15 units of electives should be courses of a technical nature at the senior and graduate levels approved by the program director.
- 6 units may be transferred from another school as electives provided that the courses were not needed for the student's bachelor's degree.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken each semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

Master of Engineering in Robotics (MEngR)

Master's Degrees

Either a thesis option or a course option may be selected. The special requirements for these options are as follows:

Course Option

This option is intended for those employed in local industry who wish to pursue a graduate degree on a part-time basis, or for full-time students who do not seek careers in research. Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree. Under the course option, students may not take ESE 599 Master's Research, and with faculty permission may take up to 3 units of ESE 500 Independent Study.

Thesis Option

This option is intended for those pursuing full-time study and engaged in research projects. Candidates for this degree must complete a minimum of 24 credit hours of course instruction and 6 credit hours of thesis research (ESE 599). Three (3) of these credit hours of thesis research may be applied toward the 15 core electrical engineering credit hours required for the MSEE program. Any of these 6 hours of thesis research may be applied as electives for the MSEE, MSSSM, MSDAS, MCEng and MEngR programs. The student must write a master's thesis and defend it in an oral examination.

Master of Engineering in Robotics

The principal goal of the Master of Engineering in Robotics (MEngR) degree program is to prepare individuals for professional practice in robotics engineering by leveraging the technical skills developed in an undergraduate engineering or physical science program. It is designed to be completed in 1.5 years, but it can be completed over a longer time period on a part-time basis. In order to finish in 1.5 years, students should take three courses (9 units) each in fall and spring semesters and four courses (12 units) in the second fall semester. For this program, the supervised project (6 units) is optional.

Required courses (12 units) for the MEngR degree include:

Code	Title	Units
ESE 446	Robotics: Dynamics and Control (Spring)	3
ESE 447	Robotics Laboratory (Fall, Spring)	3
ESE 551 or ESE 543	Linear Dynamic Systems I (Fall) Control Systems Design by State Space Methods	3
CSE 511A or CSE 517A	Introduction to Artificial Intelligence Machine Learning	3
ESE 590	Electrical & Systems Engineering Graduate Seminar (must be taken each semester)	0
Total Units		12

- Elective Courses (18 units): At least one elective course must be selected from each of the following three groups. Other courses may be selected as electives with the approval of the program director.

Optimization and Simulation Group

Code	Title	Units
ESE 403	Operations Research (Fall)	3
ESE 407	Analysis and Simulation of Discrete Event Systems (Spring)	3
ESE 415	Optimization (Spring)	3

Control Engineering Group

Code	Title	Units
ESE 441 or MEMS 4301	Control Systems (Fall) Modeling, Simulation and Control (Spring)	3
ESE 444	Sensors and Actuators (Fall)	3
ESE 425	Random Processes and Kalman Filtering (Fall)	3
ESE 543	Control Systems Design by State Space Methods (Fall)	3

ESE 552	Linear Dynamic Systems II (Spring)	3
ESE 553	Nonlinear Dynamic Systems (Spring)	3

Computer Science Group

Code	Title	Units
CSE 511A	Introduction to Artificial Intelligence	3
CSE 517A	Machine Learning	3
CSE 520S	Real-Time Systems (Fall)	3
CSE 521S	Wireless Sensor Networks	3
CSE 546T	Computational Geometry	3
CSE 553S	Advanced Mobile Robotics (Spring)	3
CSE 556A	Human-Computer Interaction Methods (Fall)	3
CSE 568M	Imaging Sensors (Spring)	3
CSE 559A	Computer Vision (Spring)	3

- Project Course: The MEngR program may include up to 6 units of project in the form of Independent Study as part of elective courses. The independent study could be in the form of a practicum or a special project and it requires approval from the program director.

Code	Title	Units
ESE 500	Independent Study (Fall, Spring and Summer)	var.
CSE 500	Independent Study (Fall, Spring and Summer)	var.
MEMS 500	Independent Study (Fall, Spring and Summer)	var.

Preparation for the MEngR Program

The required courses assume the following foundations in mechanical engineering and materials science, electrical engineering, systems engineering, and computer science. Although they do not count toward the degree program, they are recommended for those students who lack these foundations.

- MEMS 255 Engineering Mechanics II (mechanical engineering and materials science foundation, fall and spring)
- ESE 351 Signals and Systems (electrical and systems engineering foundation, fall and spring)
- CSE 501N Introduction to Computer Science (computer science foundation, fall)
- The degree requires 30 units. The courses must be 400-level or higher and they must include at least 15 units of 500-level courses.
- A maximum of 6 credits may be transferred from another institution and applied toward the Master of Science degree. Regardless of subject or level, all transfer courses are treated as electives and do not count toward the requirement

of 15 credit hours of graduate-level electrical engineering courses.

- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken each semester.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the School of Engineering & Applied Science.
- Students must have a cumulative grade point average of at least 3.2 out of a possible 4.0 over all courses applied toward the degree.

Certificate in Imaging Science & Engineering (IS&E)

Washington University has been a leader in imaging science research for over four decades, with many new medical imaging modalities, advanced applications in planetary science, and fundamental theories having been developed here. The Imaging Sciences Pathway (<https://sites.wustl.edu/imagingsciences>) in the Division of Biology and Biological Sciences in Arts & Sciences is jointly administered with the School of Engineering & Applied Science, with students pursuing degrees in departments across the university. The Imaging Science & Engineering certificate program complements the Imaging Sciences Pathway for students in the departments of Electrical & Systems Engineering, Biomedical Engineering, Computer Science & Engineering, Mechanical Engineering & Materials Science, Chemistry, Physics, and the Division of Biology and Biological Sciences. Upon completion of both the graduate degree sought and the requirements of the program, the student's transcript will include the certificate. Each department has its own requirements, but all include the Imaging Science & Engineering Seminar. The program is flexible, so students are encouraged to appeal to the program director to identify individualized programs.

The Imaging Science & Engineering certificate program is built on the strengths in imaging science throughout the university; this multidisciplinary program is constructed to expose students to the breadth of imaging research activities at Washington University. There has been an explosion of both increased bandwidth of existing imaging systems and new sensing modalities. The increase in bandwidth from sensors drives innovations in computing, image reconstruction, and image understanding. New sensing modalities present unique opportunities for young researchers to make fundamental contributions.

Medical imaging continues to comprise the largest set of applications at Washington University. The resolution of modern whole-body imaging sensors has revolutionized medicine. The development of new portable imaging modalities broadens the impact by lowering cost. Imaging science includes understanding of the underlying physical, biological, and chemical processes

that yield signals of interest. Microscopes, visible/infrared cameras, magnetic resonance, x-ray, ultrasound, and nuclear sensors provide the data used for imaging or inferring underlying processes. Imaging supports clinical diagnosis, radiation oncology, molecular, and neural imaging.

Imaging supports advances in earth and planetary science, enabling discovery from rovers on Mars, characterization of surface properties from satellites, and inferring internal phenomena in planetary objects. Modern understanding of materials science is driven in part by new imaging methods. New imaging systems for plant science seek better characterization of their biological systems.

Data rates from imaging systems demand efficient processing, manipulation, and representation. In modern imaging systems, computing and sensing often must be jointly optimized. Inference is typically based on searching for meaningful patterns in the data, along with the relative contributions of those patterns.

For more information, please refer to either the Department of Electrical & Systems Engineering website (<http://ese.wustl.edu>) or contact the department directly.

Entering and Completing the Program

Graduate students in participating departments may apply for admission to the IS&E program. Admission requires graduate standing in a participating department, a demonstrated interest in aspects of imaging, and approval of the program director.

Upon being awarded a graduate degree by their home department and by completing certain requirements of the program, students are awarded a certificate indicating their successful participation in the IS&E program. The requirements for receiving a certificate are: acceptance into the IS&E program, completion of four imaging courses approved by the program director, completion of requirements for a graduate degree in the student's home department, and participation in the Imaging Science seminar required for all students in the IS&E program.

Seminars by faculty in imaging science, others at Washington University, and experts from outside the university convey new developments and directions in the field of imaging science and its applications. These seminars also provide the opportunity for interactions among those involved in the program.

Courses of Instruction

Fundamentals underlying imaging science and engineering and the application of these fundamentals to contemporary problems of importance form the theme of the program. Relevant courses come from across the university. The program is flexible, allowing students, in consultation with their advisers and the program director, to design a program that is best for them. Below are representative courses that students in the program take.

Courses in the Imaging Sciences Pathway in the Division of Biology and Biological Sciences

- ESE 596 Seminar in Imaging Science and Engineering/CSE 596/BME 506/Physics 596 (**required**)
- BME 530A Molecular Cell Biology for Engineers
- ESE 589 Biological Imaging Technology/BME 589
- BIOL 5068 Fundamentals of Molecular Cell Biology
- BIOL 5146 Principles and Applications of Biological Imaging
- BIOL 5147/Chem 5147 Contrast Agents for Biological Imaging

Courses in Electrical & Systems Engineering

- ESE 438 Applied Optics
- ESE 520 Probability and Stochastic Processes
- ESE 524 Detection and Estimation Theory
- ESE 582 Fundamentals and Applications of Modern Optical Imaging
- ESE 585 Optical Imaging
- ESE 586A Tomographic Imaging
- ESE 587 Ultrasonic Imaging Systems
- ESE 588 Quantitative Image Processing
- ESE 589 Biological Imaging Technology
- ESE 591 Special Topics: Biomedical Topics I: Principles
- ESE 592 Special Topics: Biomedical Topics II: Imaging
- ESE 596 Seminar in Imaging Science and Engineering (**required**)

Courses in Computer Science and Engineering

- CSE 517A Machine Learning
- CSE 546T Computational Geometry
- CSE 554A Geometric Computing for Biomedicine
- CSE 559A Computer Vision
- CSE 568M Imaging Sensors
- CSE 596 Seminar in Imaging Science and Engineering (**required**)

Courses in Biomedical Imaging

- BME 502 Cardiovascular MRI — Physics to Clinical Application
- BME 503A Cell and Organ Systems Biology
- BME 504 Light Microscopy and Optical Imaging
- BME 506 Seminar in Imaging Science and Engineering (**required**)
- BME 530A Molecular Cell Biology for Engineers
- BME 589 Biological Imaging Technology
- BME 5907 Advanced Concepts in Image Science
- BME 591 Biomedical Optics I: Principles
- BME 592 Special Topics: Biomedical Topics II: Imaging
- BME 593 Computational Methods for Inverse Problems

- BME 596 Seminar in Imaging Science and Engineering (**required**)

Courses in Physics, Chemistry, and Psychology

- Physics 534 Magnetic Resonance
- Physics 589 Selected Topics in Physics I
- Physics 590.1 Seminar-Physics of Ultrasonic Imaging in Cardiovascular Medicine
- Chem 5762 Electron Spin Resonance
- Chem 576 Magnetic Resonance
- Chem 435 Nuclear and Radiochemistry Lab
- Chem 436 Radioactivity and Its Applications
- Chem 578 Nuclear Magnetic Resonance Spectroscopy
- Psych 4450 Functional Neuroimaging Methods

Website:

<https://ese.wustl.edu/graduate/degreeprograms/Pages/graduate-certificate-imaging-science-engineering.aspx>

Energy, Environmental & Chemical Engineering

The Department of Energy, Environmental & Chemical Engineering (EECE) provides integrated and multidisciplinary programs of scientific education in cutting-edge areas, including the **PhD in Energy, Environmental & Chemical Engineering**. Research and educational activities of the department are organized into four clusters: aerosol science & engineering; engineered aquatic processes; multiscale engineering; metabolic engineering & systems biology. These overlapping clusters address education and research in four thematic areas: energy; environmental engineering science; advanced materials; and sustainable technology for public health and international development. In addition to the core faculty in the department, faculty in the schools of Medicine, Arts & Sciences, Business, Law, and Social Work collaborate to provide students with a holistic education and to address topical problems of interest.

Two master's programs are offered through the department: **Master of Engineering in Energy, Environmental & Chemical Engineering (MEng)** and **Master of Engineering in Energy, Environmental & Chemical Engineering/Master of Business Administration (MEng/MBA)**. The MEng degree provides students with critical scientific and engineering skill sets; leadership training for management, economics, and policy decision; and the opportunity to specialize in one of five pathways. The MEng/MBA is a dual degree between the School of Engineering & Applied Science and the Olin Business School which provides engineering and business approaches to issues of sustainability, energy, the environment, and corporate social responsibility. Interested students must apply and be accepted to both programs before admission is provided to the MEng/MBA dual degree program.

The department is a key participant in the university's Energy, Environment & Sustainability (<http://sustainability.wustl.edu>) initiative and supports both the International Center for Energy, Environment and Sustainability (InCEES (<http://incees.wustl.edu>)) and the McDonnell Academy Global Energy and Environment Partnership (MAGEEP (<http://mageep.wustl.edu>)). Major externally funded research centers in the department include the Consortium for Clean Coal Utilization (<http://cleancoal.wustl.edu>), the Nano Research Facility (NRF) and Jens Environmental Molecular and Nanoscale Analysis Laboratory (Jens Lab) (<https://nano.wustl.edu>), and the Solar Energy Research Institute for India and the United States (SERIUS (<http://www.serius.org>)).

Phone: 314-935-5548

Website: <https://eece.wustl.edu/graduate/programs>

Faculty

Chair and Endowed Professor

Pratim Biswas (<https://engineering.wustl.edu/Profiles/Pages/Pratim-Biswas.aspx>)

Lucy and Stanley Lopata Professor

PhD, California Institute of Technology

Aerosol science and engineering, air quality and pollution control, nanotechnology, environmentally benign energy production

Endowed Professors

Richard L. Axelbaum (<https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx>)

Stifel and Quinette Jens Professor

PhD, University of California, Davis

Combustion, advanced energy systems, clean coal, aerosols, nanoparticle synthesis, rechargeable battery materials, thermal science

Milorad P. Dudukovic (<https://engineering.wustl.edu/Profiles/Pages/Milorad-Dudukovic.aspx>)

Laura and William Jens Professor

PhD, Illinois Institute of Technology

Chemical reaction engineering, multiphase reactors, visualization of multiphase flows, tracer methods, environmentally benign processing

Daniel E. Giammar (<https://engineering.wustl.edu/Profiles/Pages/Daniel-Giammar.aspx>)

Walter E. Browne Professor of Environmental Engineering

PhD, California Institute of Technology

Aquatic chemistry, environmental engineering, water quality, water treatment

Vijay Ramani (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=108>)

Roma B. and Raymond H. Wittcoff Distinguished University

Professor of Environment Engineering

PhD, University of Connecticut, Storrs

Electrochemical engineering, energy conversion

Professors

Young-Shin Jun (<https://engineering.wustl.edu/Profiles/Pages/Young-Shin-Jun.aspx>)

Director of Graduate Studies

PhD, Harvard University

Aquatic processes, molecular issues in chemical kinetics, environmental chemistry, surface/physical chemistry, environmental engineering, biogeochemistry, nanotechnology

Palghat A. Ramachandran (<https://engineering.wustl.edu/Profiles/Pages/Palghat-Ramachandran.aspx>)

PhD, University of Bombay

Chemical reaction engineering, applied mathematics, process modeling, waste minimization, environmentally benign processing

Yinjie Tang (<https://engineering.wustl.edu/Profiles/Pages/Yinjie-Tang.aspx>)

Director of Undergraduate Studies

PhD, University of Washington, Seattle

Metabolic engineering, bioremediation

Jay R. Turner (<https://engineering.wustl.edu/Profiles/Pages/Jay-Turner.aspx>)

Vice Dean for Education

DSc, Washington University

Air quality planning and management; aerosol science and engineering, green engineering

Jian Wang (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=126>)

PhD, California Institute of Technology

Aerosol properties and processes, nucleation and new particle formation, aerosols in the marine environment, effects of aerosols on cloud microphysical properties and macrophysical structure, and development of advanced aerosol instruments

Associate Professors

John Fortner (<https://engineering.wustl.edu/Profiles/Pages/John-Fortner.aspx>)

InCEES Career Development Associate Professor

PhD, Rice University

Environmental engineering, aquatic processes, water treatment, remediation, and environmental implications and applications of nanomaterials

John T. Gleaves (<https://engineering.wustl.edu/Profiles/Pages/John-Gleaves.aspx>)

PhD, University of Illinois

Heterogeneous catalysis, particle chemistry

Tae Seok Moon (<https://engineering.wustl.edu/Profiles/Pages/Tae-Seok-Moon.aspx>)
PhD, Massachusetts Institute of Technology
Metabolic engineering and synthetic biology

Brent Williams (<https://engineering.wustl.edu/Profiles/Pages/Brent-Williams.aspx>)
Raymond R. Tucker Distinguished InCEES Career Development Associate Professor
PhD, University of California, Berkeley
Aerosols, global climate issues, atmospheric sciences

Fuzhong Zhang (<https://engineering.wustl.edu/Profiles/Pages/Fuzhong-Zhang.aspx>)
PhD, University of Toronto
Metabolic engineering, protein engineering, synthetic and chemical biology

Assistant Professors

Peng Bai (<https://engineering.wustl.edu/Profiles/Pages/Peng-Bai.aspx>)
PhD, Tsinghua University, China
Develop next-generation batteries, probe the in situ electrochemical dynamics of miniature electrodes down to nanoscales, capture the heterogeneous and stochastic nature of advanced electrodes, and identify the theoretical pathways and boundaries for the rational design of materials, electrodes and batteries through physics-based mathematical modeling and simulation

Rajan Chakrabarty (<https://engineering.wustl.edu/Profiles/Pages/Rajan-Chakrabarty.aspx>)
PhD, University of Nevada, Reno
Characterizing the radiative properties of carbonaceous aerosols in the atmosphere; and researching gas phase aggregation of aerosols in cluster-dense conditions

Marcus Foston (<https://engineering.wustl.edu/Profiles/Pages/Marcus-Foston.aspx>)
PhD, Georgia Institute of Technology
Utilization of biomass resources for fuel and chemical production, renewable synthetic polymers

Fangqiong Ling (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=178>)
PhD, University of Illinois at Urbana-Champaign
Microbial ecosystem analysis and modelling, process modelling, machine learning, NextGen sequencing bioinformatics, environmental microbiology, and bioreactor design

Kimberly M. Parker (<https://engineering.wustl.edu/Profiles/Pages/Kimberly-Parker.aspx>)
PhD, Stanford University
Investigation of environmental organic chemistry in natural and engineered systems

Elijah Thimsen (<https://engineering.wustl.edu/Profiles/Pages/Elijah-Thimsen.aspx>)
PhD, Washington University
Gas-phase synthesis of inorganic nanomaterials for energy applications, and novel plasma synthesis approaches

Research Associate Professor

Tianxiang Li
PhD, University of Kentucky
Combustion and applications in energy, pollutant control, biofuel synthesis, flame synthesis of nanomaterials

Research Assistant Professor

Benjamin Kumfer
DSc, Washington University
Advanced coal technologies, biomass combustion, aerosol processes and health effects of combustion-generated particles

Lecturers

Janie Brennan
PhD, Purdue University
Biomaterials, synthetic biology, engineering education

Trent Silbaugh
PhD, University of Washington
Chemical engineering

Joint Faculty

Doug Allen
PhD, Purdue University
USDA Research Scientist, Danforth Plant Sciences Center
Metabolic networks of oilseed plants

Nathan Ravi
PhD, Virginia Polytechnic Institute
Cataract, ocular biomaterials

Adjunct Faculty

Robert Heider
MME, Washington University
Process control and process design

Timothy Michels
MA, Washington University
Energy economics, building construction and equipment sciences

Gary Moore
MS, Missouri University of Science and Technology
Environmental management

Nicholas J. Nissing
BS, Washington University
Product development and process design

Research Associate

Raymond Ehrhard

BS, Missouri University of Science and Technology
Water and wastewater treatment technologies, process energy management

Senior Professor

Rudolf B. Husar

PhD, University of Minnesota
Environmental informatics, aerosol science and engineering

Degree Requirements

Please visit the following pages for information about the

- Doctor of Philosophy (PhD) (p. 60)
- Master of Engineering (MEng) (p. 61)
- Combined MEng/MBA (given jointly with Olin Business School) (p. 61)

Courses

Visit online course listings to view semester offerings for E44 EECE (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E44&crslvl=5:8>).

E44 EECE 500 Independent Study

Independent investigation on topic of special interest. Interested students are encouraged to approach and engage faculty to develop a topic of interest. A form declaring the agreement must be filed in the departmental office. Petitions are generally considered in the semester preceding the independent study experience. Prerequisite: graduate-level standing. Credit variable, maximum 9 units.

E44 EECE 501 Transport Phenomena in EECE

The aim of the course is for students to develop skills in applying principles of momentum, heat and mass transport in an unified manner to problems encountered in the areas of energy, environmental and chemical processes. A systems approach is followed so that the general principles can be grasped, and the skills to develop mathematical models of seemingly different processes are emphasized. This provides the students with a general tool which they can apply later in their chosen field of research. (Prior to FL2015, this course was numbered: E33 501.) Credit 3 units.

E44 EECE 502 Advanced Thermodynamics in EECE

The objective of this course is to understand classical thermodynamics at a deeper level than is reached during typical undergraduate work. Emphasis is placed on solving problems relevant to chemical engineering materials science. Prerequisite: E63 ChE 320 or E44 203 or equivalent. (Prior to FL2015, this course was numbered: E33 511.) Credit 3 units.

E44 EECE 503 Mathematical Methods in EECE

The course introduces students to mathematical principles essential for graduate study in any engineering discipline. Applied mathematical concepts are demonstrated by applications to various areas in energy, environmental, biomedical, chemical, mechanical, aerospace, electrical and civil engineering. (Prior to FL2015, this course was numbered: E33 502.)

Credit 3 units.

E44 EECE 504 Aerosol Science and Technology

Fundamental properties of particulate systems — physics of aerosols, size distributions, mechanics and transport of particles: diffusion, inertia, external force fields. Visibility and light scattering. Aerosol dynamics — coagulation, nucleation, condensation. Applications to engineered systems: nanoparticle synthesis, atmospheric aerosols, combustion aerosols, pharmaceutical aerosols. Prerequisites: EECE 301, ESE 318 and 319. (Prior to FL2015, this course was numbered: E63 518.) Credit 3 units. EN: TU

E44 EECE 505 Aquatic Chemistry

Aquatic chemistry governs aspects of the biogeochemical cycling of trace metals and nutrients, contaminant fate and transport, and the performance of water and wastewater treatment processes. This course examines chemical reactions relevant to natural and engineered aquatic systems. A quantitative approach emphasizes the solution of chemical equilibrium and kinetics problems. Topics covered include chemical equilibrium and kinetics, acid-base equilibria and alkalinity, dissolution and precipitation of solids, complexation of metals, oxidation-reduction processes, and reactions on solid surfaces. A primary objective of the course is to be able to formulate and solve chemical equilibrium problems for complex environmental systems. In addition to solving problems manually to develop chemical intuition regarding aquatic systems, software applications for solving chemical equilibrium problems are also introduced. Prerequisite: Chem 112A. (Prior to FL2015, this course was numbered: E33 443/543.)

Credit 3 units. EN: TU

E44 EECE 506 Bioprocess Engineering I: Fundamentals & Applications

The course covers the fundamentals and provides the basic knowledge needed to understand and analyze processes in biotechnology in order to design, develop and operate them efficiently and economically. This knowledge is applied to understand various applications and bioprocesses, such as formation of desirable bio and chemical materials and products, production of bioenergy, food processing and waste treatment. The main objective of the course is to introduce the essential concepts and applications of bioprocessing to students of diverse backgrounds. An additional project is required to obtain graduate credit. Prerequisites: L41 Biol 2960 or equivalent or permission of instructor. (Prior to FL2015, this course was numbered: E63 453/553.)

Credit 3 units. EN: TU

E44 EECE 507 Kinetics and Reaction Engineering Principles

The course is aimed at a modern multiscale treatment of kinetics of chemical and biochemical reactions and application of these fundamentals to analyze and design reactors. Application of reaction engineering principles in the areas related to energy generation, pollution prevention, chemical and biochemical

processes are studied and illustrated with case studies and computer models. Description of the role of mass and heat transport in reacting systems is also provided with numerous examples. (Prior to FL2015, this course was numbered: E33 503.)

Credit 3 units.

E44 EECE 508 Research Rotation

First-year doctoral students in EECE should undertake research rotation as a requirement prior to choosing a permanent research adviser. The rotation requires the student to work under the guidance of a faculty member. (Prior to FL2015, this course was numbered: E33 508.)

E44 EECE 509 Seminar in Energy, Environmental, and Chemical Engineering

All graduate students in EECE should attend the Departmental Seminar Series to gain exposure in various diverse fields of research. Students are also expected to participate in journal clubs and other discussion formats to discuss topical research areas. The course is required of all graduate students every semester of residency in the program. (Prior to FL2015, this course was numbered: E33 509.)

Credit 1 unit.

E44 EECE 510 Advanced Topics in Aerosol Science & Engineering

This course is focused on discussion of advanced topics in aerosol science and engineering and its applications in a variety of fields — materials science, chemical engineering, mechanical engineering, and environmental engineering. Prerequisite: EECE 504. (Prior to FL2015, this course was numbered: E63 592A.)

Credit 3 units. EN: TU

E44 EECE 512 Combustion Phenomena

Introduction to fundamental aspects of combustion phenomena including relevant thermochemistry, fluid mechanics, and transport processes. Emphasis is on elucidation of the physico-chemical processes, problem formulation, and analytical techniques. Topics covered include ignition, extinction, diffusion flames, particle combustion, deflagrations, and detonations. Prerequisites: graduate standing or permission of instructor. (Prior to FL2015, this course was numbered: E33 5404.)

Credit 3 units. EN: TU

E44 EECE 513 Topics in Nanotechnology

This course is focused on the discussion of topics in nanotechnology — with a focus on nanoparticles and their applications in a variety of fields — materials science, chemical engineering, mechanical engineering, environmental engineering, medicine. (Prior to FL2015, this course was numbered: E63 526.)

Credit 3 units. EN: TU

E44 EECE 514 Atmospheric Science and Climate

This course covers current research topics in atmospheric chemistry and climate change. Topics include atmospheric composition, chemistry, transport, dynamics, radiation, greenhouse gases, natural and anthropogenic primary pollution sources and secondary aerosol production, and measurement techniques. Focus is placed on how our atmosphere and climate are altered in a world of changing energy production and land

use. Prerequisites: Chem 112A, Physics 118 or 198, and junior or higher standing. (Prior to FL2015, this course was numbered: E33 547.)

Credit 3 units. EN: TU

E44 EECE 515 Dynamics of Air Pollution

Physicochemical processes governing the dynamics of pollutants from point and non-point sources: generation, transport and decay. Application of fundamental thermodynamics, mass/heat transfer and fluid mechanics principles to environmental systems. Prerequisites: EECE 203, ESE 317 or ESE 318 and 319, and EECE 505, or equivalent, or permission of instructor. (Prior to FL2015, this course was numbered: E63 510.)

Credit 3 units. EN: TU

E44 EECE 516 Measurement Techniques for Particle Characterization

The purpose of this course is to introduce students to the principles and techniques of particle measurement and characterization. Practical applications of particle technology include air pollution measurement, clean manufacturing of semiconductors, air filtration, indoor air quality, particulate emission from combustion sources and so on. The course focuses on (1) integral moment measurement techniques, (2) particle sizing and size distribution measuring techniques, and (3) particle composition measurement techniques. The related issues such as particle sampling and transportation, the instrument calibration, and particle standards also are covered. (Prior to FL2015, this course was numbered: E63 563.)

Credit 3 units. EN: TU

E44 EECE 518 Sustainable Air Quality

Introduction to sustainability and sustainable air quality. Systems science as an organizing principle for air quality management. Setting of air quality goals. Observing the status and trends. Establishing causal factors: energy use and chemical processing. Natural sources and variability. Corrective actions to reach air quality goals. Process design for emission reductions. Adoptive response to air pollution episodes. A web-based class project is conducted through the semester. (Prior to FL2015, this course was numbered: E63 549.)

Credit 3 units. EN: TU

E44 EECE 531 Environmental Organic Chemistry

Fundamental, physical-chemical examination of organic molecules (focused on anthropogenic pollutants) in aquatic (environmental) systems. Students learn to calculate and predict chemical properties that are influencing the partitioning of organic chemicals within air, water, sediments and biological systems. This knowledge is based on understanding intermolecular interactions and thermodynamic principles. Mechanisms of important thermochemical, hydrolytic, redox, and biochemical transformation reactions are also investigated, leading to the development of techniques (such as structure-reactivity relationships) for assessing environmental fate or human exposure potential. Prerequisite: Chem 112A. (Prior to FL2015, this course was numbered: E33 448/548.)

Credit 3 units. EN: TU

E44 EECE 533 Physical and Chemical Processes for Water Treatment

Water treatment is examined from the perspective of the physical and chemical unit processes used in treatment. The theory and

fundamental principles of treatment processes are covered and are followed by the operation of treatment processes. Processes covered include gas transfer, adsorption, precipitation, oxidation-reduction, flocculation, sedimentation, filtration, and membrane processes. (Prior to FL2015, this course was numbered: E33 588.)

Credit 3 units. EN: TU

E44 EECE 534 Environmental Nanochemistry

This course involves the study of nanochemistry at various environmental interfaces, focusing on colloid, nanoparticle, and surface reactions. The course also (1) examines the thermodynamics and kinetics of nanoscale reactions at solid-water interfaces in the presence of inorganic or organic compounds and microorganisms; (2) investigates how nanoscale interfacial reactions affect the fate and transport of contaminants; (3) introduces multidisciplinary techniques for obtaining fundamental information about the structure and reactivity of nanoparticles and thin films, and the speciation or chemical form of environmental pollutants at the molecular scale; (4) explores connections between environmental nanochemistry and environmental kinetic analysis at larger scales. This course helps students attain a better understanding of the relationship between nanoscience/technology and the environment — specifically how nanoscience could potentially lead to better water treatments, more effective contaminated-site remediation, or new energy alternatives. (Prior to FL2015, this course was numbered: E33 534.)

Credit 3 units. EN: TU

E44 EECE 536 Computational Chemistry of Molecular and Nanoscale Systems

This course explores the structure, properties and reactivity of molecular and nanoscale systems in engineering using computational chemistry tools. The science behind density functional theory (DFT) calculations and molecular dynamics (MD) simulations is explained and applied in the context of multiscale modeling. Special emphasis is placed on solid-state materials and aqueous/biological systems found in engineering. Students are encouraged to apply the methods discussed in class to their own research topics. Prerequisites: EECE 203 and 204, or permission of the instructor. (Prior to FL2015, this course was numbered: E33 591.)

Credit 3 units. EN: TU

E44 EECE 551 Metabolic Engineering and Synthetic Biology

Synthetic Biology is a transformative view of biology from "observation approach" to "synthesis approach." It is a new "engineering" discipline and aims to make the engineering of new biological function predictable, safe and quick. It will pave a wide range of applications to transform our views on production of sustainable energy and renewable chemicals, environmental problems, and human disease treatments. The field intersects with Metabolic Engineering in areas such as the design of novel pathways and genetic circuits for product generation and toxic chemical degradation. In this course, the field and its basis are introduced. First, relevant topics in biology, chemistry, physics and engineering are covered. Second, students will participate in brain-storming and discussion on new biology-based systems. Last, students will design and present new synthetic biology systems to solve real-world problems. (Prior to FL2015, this course was numbered: E33 596A.) No prerequisite. Both undergrad and graduate students can take this course.

Credit 3 units. EN: TU

E44 EECE 552 Biomass Energy Systems and Engineering

This course offers background in the organic chemistry, biology and thermodynamics related to understanding the conversion of biomass. In addition, it includes relevant topics relating to biomass feedstock origin, harvest, transportation, storage, processing and pretreatment along with matters concerning thermo- and biochemical conversion technologies required to produce fuels, energy, chemicals and materials. Also, various issues with respect to biomass characterization, economics and environmental impact are discussed. The main objective of the course is to introduce concepts central to a large-scale integrated biomass bioconversion system. (Prior to FL2015, this course was numbered: E33 495D/595D.)

Credit 3 units. EN: TU

E44 EECE 554 Molecular Biochemical Engineering

This course is set for junior-level graduate students to bridge the gap between biochemical engineering theory and academic research in bioengineering. It covers common molecular biotechnologies (molecular biology, microbiology, recombinant DNA technology, protein expression, etc.), biochemical models (enzyme catalysis, microbial growth, bioreactor, etc.) and bioengineering methodologies (protein engineering, expression control systems, etc.). These theories and technologies are introduced in a manner closely related to daily academic research or biochemical industry. Areas of application include biofuel and chemical production, drug discovery and biosynthesis, bioremediation, and environmental applications. This course also contains a lab section (20–30%) that requires students to apply the knowledge learned to design experiments, learn basic experimental skills and solve current research problems. Prerequisites: EECE 101, Biol 2960, Biol 4810. (Prior to FL2015, this course was numbered: E33 595C.)

Credit 3 units. EN: TU

E44 EECE 556 Bioenergy

A broad overview of the flow of energy, captured from sunlight during photosynthesis, in biological systems, and current approaches to utilize the metabolic potentials of microbes and plants to produce biofuels and other valuable chemical products. An overall emphasis is placed on the use of large-scale genomic, transcriptomic and metabolomic datasets in biochemistry. The topics covered include photosynthesis, central metabolism, structure and degradation of plant lignocellulose, and microbial production of liquid alcohol, biodiesel, hydrogen & other advanced fuels. Course meets during the second half of the spring semester. Prerequisites: Biol 4810 or permission of instructor. (Prior to FL2015, this course was numbered: E33 4830/5830.)

Credit 2 units.

E44 EECE 571 Industrial and Environmental Catalysis

Major industrial and environmental catalytic processes. Principal theories of heterogeneous catalysis. Experimental methods and techniques used to develop modern catalytic systems. Examples from the petrochemical industry, automotive exhaust systems and industrial emissions abatement. Prerequisites: Chem 112, 262. (Prior to FL2015, this course was numbered: E63 525.)

Credit 3 units. EN: TU

E44 EECE 572 Advanced Transport Phenomena

Analytical tools in transport phenomena: Scaling, perturbation and stability analysis. Numerical computations of common

transport problem with MATLAB tools. Low Reynolds number flows and applications to microhydrodynamics. Turbulent flow analysis and review of recent advances in numerical modeling of turbulent flows. Convective heat and mass transfer in laminar and turbulent flow systems. Introduction to two phase flow and multiphase reactors. Pressure-driven transport and transport in membranes, electrochemical systems, double layer effects and flow in microfluid devices. Prerequisites: EECE 501 (Transport phenomena) or equivalent senior level courses in fluid mechanics and heat transfer. (Prior to FL2015, this course was numbered: E63 514.)
Credit 3 units. EN: TU

E44 EECE 574 Electrochemical Engineering

This course will teach the fundamentals of electrochemistry and the application of the same for analyzing various electrochemical energy sources/devices. The theoretical frameworks of current-potential distributions, electrode kinetics, porous electrode and concentrated solution theory will be presented in the context of modeling, simulation and analysis of electrochemical systems. Applications to batteries, fuel cells, capacitors, copper deposition will be explored. Pre-/corequisites: EECE 501-502 (or equivalent), or permission of instructor. (Prior to FL2015, this course was numbered: E33 589.)
Credit 3 units.

E44 EECE 576 Chemical Kinetics and Catalysis

This course reflects the fast, contemporary progress being made in decoding kinetic complexity of chemical reactions, in particular heterogeneous catalytic reactions. New approaches to understanding relationships between observed kinetic behaviour and reaction mechanism will be explained. Present theoretical and methodological knowledge will be illustrated by many examples taken from heterogeneous catalysis (complete and partial oxidation), combustion and enzyme processes. Prerequisite: senior or graduate student standing, or permission of instructor.
Credit 3 units. EN: TU

E44 EECE 591 Energy and Buildings

There is a \$2 trillion U.S. market in energy efficiency with paybacks of 4-5 years. This course is an introduction to energy use in the built environment and means and methods for evaluating and harvesting these financial benefits. It is based on fundamentals of energy usage in building systems. Building sciences for architectural envelope, heating and cooling systems, lighting and controls. Building/weather interaction and utility weather regression analyses. Building dynamics and rates of change in energy usage. Students work in groups to perform an energy audit for a building on campus. Prerequisite: senior or graduate student standing, or permission of instructor. (Prior to FL2015, this course was numbered: E33 495/595.)
Credit 3 units.

E44 EECE 593 Energy and Environment

This course sets out to instruct the student on how to understand decision-making regarding energy and the environment, and provides a unique educational experience, wherein the challenges and potential solutions to meeting future energy needs are clearly elucidated via lectures and experiential learning. Topics include: overview of energy and the environment and associated challenges; description of power generation from coal, natural gas, biomass, wind, solar, hydro, geothermal and nuclear; political, environmental

and social considerations; regulations, economics, decision-making; students gain experience with software capable of analyzing renewable energy projects worldwide, from backyard to power-plant scale systems. (Prior to FL2015, this course was numbered: E33 500A.)
Credit 3 units.

E44 EECE 597 EECE Project Management

An introduction to the theory and practice of engineering project management, with an emphasis on projects related to environmental protection and occupational health and safety. Topics include: project definition and justification; project evaluation and selection; financial analysis and cost estimation; project planning, including scheduling, resourcing and budgeting; project oversight, auditing and reporting; and effective project closure. Students will be introduced to commonly used project management tools and systems, such as work breakdown structures, network diagrams, Gantt charts, and project management software. Topics will also include project management in different organizational structures and philosophies; creating effective project teams; and managing projects in international settings. Prerequisites: enrolled in MEng program; senior or higher standing.
Credit 3 units.

E44 EECE 599 Master's Research

Credit variable, maximum 9 units.

E44 EECE 600 Doctoral Research

Credit variable, maximum 9 units.

E44 EECE 883 Master's Continuing Student Status

E44 EECE 885 Master's Nonresident

Doctor of Philosophy (PhD) in Energy, Environmental & Chemical Engineering (EECE)

The doctoral degree requires a total of 72 credits beyond the bachelor's degree. Of these, a minimum of 36 must be graduate courses and a minimum of 30 must be doctoral thesis research units. To be admitted to candidacy, students must have completed at least 18 credits at Washington University, have an overall GPA equal to or greater than 3.25, and pass the qualifying examination. All students are required to enroll in the department seminar every semester to receive passing grades. The first-year students must complete the core curriculum, perform two research rotations, and find a permanent research adviser. Then, within 18 months after the qualifying exam (generally in their third year), students should defend their thesis proposal.

After the successful proposal defense, students should provide the research updates through annual meetings or reports with their thesis committee until their graduation. While conducting doctoral research, students should perform professionally in a

research lab including compliance with safety and regulatory requirements for their research projects. During the doctoral program, students must satisfy their fundamental and advanced teaching requirements by participating in mentored teaching experiences in the department for two or three semesters, by attending professional development workshops from the Teaching Center, and by presenting at least two formal presentations at the local level or at a national or international conference. Upon completion of the thesis, students must present the thesis in a public forum and successfully defend the thesis before their thesis committee.

For more detailed guidelines, please refer to the EECE doctoral studies handbook available on the EECE Graduate Degree Programs (<https://eece.wustl.edu/graduate/programs/Pages/PhD-Energy-Environmental-Chemical-Eng.aspx>) webpage.

Master of Engineering (MEng) in Energy, Environmental & Chemical Engineering (EECE)

This 12-month professional graduate degree is a master's program based in course work for students interested in state-of-the-art practice in environmental engineering, energy systems, and chemical engineering. The master's degree provides students with critical scientific and engineering skill sets; leadership training for management, economics, and policy decision; and the opportunity to specialize in specific pathways. The curriculum is geared to enhance skill sets for practice in industry.

The program consists of 30 units, with a total of five required core courses in four areas:

- Technical Core (6 units)
- Mathematics (3 units)
- Project Management (3 units)
- Social, Legal, and Policy Aspects (3 units)

Elective courses (400- or 500-level) are selected with the approval of the academic adviser. All courses comprising the required 30 credits must be taken for a grade (i.e., cannot be taken pass/fail), and a minimum GPA of 2.70 is required for graduation.

Pathways composed of specific elective courses can be completed to result in a certificate of specialization. Available pathways follow:

- Advanced Energy Technologies
- Bioengineering and Biotechnology
- Environmental Engineering Science
- Energy and Environmental Nanotechnology
- Energy and Environmental Management

For more detailed information, please visit the MEng in EECE (<https://eece.wustl.edu/graduate/programs/Pages/MEng-Energy-Environmental-Chemical-Eng.aspx>) webpage.

Combined Master of Engineering/Master of Business Administration (MEng/MBA)

In recent years, student interest has grown rapidly in the intersection between engineering and business approaches to issues of sustainability, energy, the environment, and corporate social responsibility. An interdisciplinary approach is necessary to address these issues with innovative, critical thinking, leading to practical, effective solutions. This combined program, the Master of Engineering in Energy, Environmental & Chemical Engineering/Master of Business Administration (MEng/MBA), between the School of Engineering & Applied Science and Olin Business School is well positioned to address this critical intersection.

The Olin MBA curriculum offers a comprehensive set of required and elective courses built upon a foundation of critical-thinking and leadership skills. Olin MBAs are able to shape the curriculum to meet their unique personal objectives, incorporating the MEng degree requirements.

Both MEng and MBA degrees will be awarded simultaneously at the completion of the program.

Please visit the Olin Combined Programs (<http://www.olin.wustl.edu/EN-US/academic-programs/full-time-MBA/academics/joint-degrees/Pages/wash-u-graduate-programs.aspx>) webpage and the EECE MEng/MBA webpage (<https://eece.wustl.edu/graduate/programs/Pages/MEngMBA-Program.aspx>) for details.

Imaging Science (Interdisciplinary PhD)

The PhD program in Imaging Science at Washington University in St. Louis is **one of only two** such programs in the U.S. and offers an interdisciplinary curriculum that focuses on the technology of imaging with applications ranging from cancer diagnosis to virtual reality.

What is Imaging Science?

Imaging Science is an interdisciplinary academic discipline that broadly addresses the design and optimization of imaging systems and the extraction of information from images. It builds on contributions from traditional fields including biomedical engineering, electrical engineering, and computer science, as well as from physics, applied mathematics, biology and chemistry.

What can you do with a PhD in Imaging Science?

The high demand for personnel with training in imaging science is reflected in government policy and funding opportunities. Many academic, industrial, and national laboratory positions exist for highly qualified candidates. Graduates of the program will be prepared for careers in academic research or in industry that requires expertise in the quantitative principles of imaging.

Curriculum Focus

- mathematical and computational principles of image formation
- image analysis
- image understanding
- image quality assessment

This interdisciplinary program is unique and brings together expert faculty from the School of Engineering & Applied Science (<https://engineering.wustl.edu/Pages/home.aspx>) and the School of Medicine (<https://medicine.wustl.edu>) to provide students the freedom and flexibility to learn from leading imaging experts and engage in impactful research.

History

Washington University has been a leader in the technology and advancement of imaging science for more than 125 years. In the 1920s, Washington University researchers were the first to use X-rays to view the gallbladder. In the 1970s, research by Michel Ter-Pogossian at the university's Mallinckrodt Institute of Radiology led to the development of the PET scanner.

Website: <https://engineering.wustl.edu/departments-faculty/interdisciplinary-degree-programs/imaging-science/>

Faculty

Mark Anastasio (<https://engineering.wustl.edu/Profiles/Pages/Mark-Anastasio.aspx>)

Imaging Science Program Director
Professor
PhD, University of Chicago
Biomedical Engineering

Sam Achilefu (<http://orl.wustl.edu/index.php?id=122>)

Michel M. Ter-Pogossian Professor of Radiology
University of Nancy, France
Radiology; Biomedical Engineering

Hongyu An (<https://www.mir.wustl.edu/research/research-laboratories/biomedical-magnetic-resonance-laboratory-bmrl/people/bio-an>)

Associate Professor
PhD, Washington University
Radiology; Biomedical Engineering

Beau Ances (<https://neuro.wustl.edu/research/research-labs-2/ances-laboratory/team>)

Professor
MD, University of Pennsylvania
PhD, University of Pennsylvania
Neurology; Biomedical Engineering

Martin Arthur (<https://engineering.wustl.edu/Profiles/Pages/Martin-Arthur.aspx>)

Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, University of Pennsylvania
Electrical & Systems Engineering

Deanna Barch (<https://psychweb.wustl.edu/people/deanna-barch>)

Gregory B. Couch Professor of Psychiatry
PhD, University of Illinois
Psychological & Brain Sciences; Biomedical Engineering

Phil Bayly (<https://engineering.wustl.edu/Profiles/Pages/Philip-Bayly.aspx>)

Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Duke University
Mechanical Engineering & Materials Science

Aaron Bobick (<https://engineering.wustl.edu/Profiles/Pages/Aaron-Bobick.aspx>)

James M. McKelvey Professor and Dean
PhD, Massachusetts Institute of Technology
Computer Science & Engineering

Frank Brooks (<https://bme.wustl.edu/faculty/Pages/Frank-Brooks.aspx>)

Research Assistant Professor
PhD, Washington University
Biomedical Engineering

Ayan Chakrabarti (<https://engineering.wustl.edu/Profiles/Pages/Ayan-Chakrabarti.aspx>)

Assistant Professor
PhD, Harvard University
Computer Science & Engineering

Hong Chen (<https://engineering.wustl.edu/Profiles/Pages/Hong-Chen.aspx>)

Assistant Professor
PhD, University of Washington
Biomedical Engineering

Joe Culver (<https://www.mir.wustl.edu/research/research-laboratories/optical-radiology-laboratory-orl/people/joseph-culver>)

Professor
PhD, University of Pennsylvania
Radiology; Biomedical Engineering

James Fitzpatrick (<http://neurosci.wustl.edu/people/faculty/james-fitzpatrick>)

Associate Professor
PhD, University of Bristol, United Kingdom
Cell Biology & Physiology; Biomedical Engineering

Michael Gach (<https://radonc.wustl.edu/faculty/michael-gach>)
Associate Professor

PhD, University of Pittsburgh
Radiation Oncology; Biomedical Engineering

Roch Guérin (<https://engineering.wustl.edu/Profiles/Pages/Roch-Gu%C3%A9rin.aspx>)

Harold B. and Adelaide G. Welge Professor of Computer Science
PhD, California Institute of Technology
Computer Science & Engineering

Dennis Hallahan (<https://wuphysicians.wustl.edu/for-patients/find-a-physician/dennis-e-hallahan>)

Elizabeth H. and James S. McDonnell III Distinguished Professor of Medicine
MD, Rush University
Radiation Oncology; Biomedical Engineering

Tim Holy (<http://neurosci.wustl.edu/people/faculty/timothy-holy>)

Alan A. and Edith L. Wolff Professor of Neuroscience
PhD, Princeton University
Neuroscience; Biomedical Engineering

Geoff Hugo (<https://radonc.wustl.edu/faculty/geoffrey-hugo-phd>)
Professor

PhD, University of California, Los Angeles
Radiation Oncology; Biomedical Engineering

Abhinav Jha (<https://engineering.wustl.edu/Profiles/Pages/Abhinav-Jha.aspx>)

Assistant Professor
PhD, University of Arizona
Biomedical Engineering; Radiology

Tao Ju (<https://engineering.wustl.edu/Profiles/Pages/Tao-Ju.aspx>)

Professor
PhD, Rice University
Computer Science & Engineering

Ulugbek Kamilov (<https://engineering.wustl.edu/Profiles/Pages/Ulugbek-Kamilov.aspx>)

Assistant Professor
PhD, École Polytechnique Fédérale de Lausanne, Switzerland
Computer Science & Engineering; Electrical & Systems Engineering

Gregory Lanza (<https://cardiology.wustl.edu/faculty/gregory-m-lanza-md-phd-facc>)

Oliver M. Langenberg Chair, Distinguished Professor of the Science and Practice of Medicine
MD, Northwestern University
PhD, University of Georgia
Medicine; Biomedical Engineering

Richard Laforest (<https://www.mir.wustl.edu/research/research-laboratories/radiological-chemistry-and-imaging-laboratory-rcil/people/richard-laforest>)

Associate Professor
PhD, University of Laval, Canada
Radiology

Matthew Lew (<https://engineering.wustl.edu/Profiles/Pages/Matthew-Lew.aspx>)

Assistant Professor
PhD, Stanford University
Electrical & Systems Engineering

Harold Li (<https://radonc.wustl.edu/faculty/harold-li>)

Associate Professor
PhD, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Radiation Oncology; Biomedical Engineering

Hua Li (<https://radonc.wustl.edu/faculty/hua-li-phd>)

Assistant Professor
PhD, Huazhong University of Science and Technology, China
Radiation Oncology; Biomedical Engineering

Daniel Marcus (<https://www.mir.wustl.edu/research/research-support-facilities/neuroimaging-informatics-analysis-center-niac/our-staff/niac-staff-dan-marcus>)

Associate Professor
PhD, Washington University
Radiology; Biomedical Engineering

Sasa Mutic (<https://radonc.wustl.edu/faculty/sasa-mutic>)
Professor

PhD, University of Missouri-Columbia
Radiation Oncology; Biomedical Engineering

Arye Nehorai (<https://engineering.wustl.edu/Profiles/Pages/Arye-Nehorai.aspx>)

Eugene and Martha Lohman Professor of Electrical Engineering
PhD, Stanford University
Electrical & Systems Engineering

Jody O'Sullivan (<https://engineering.wustl.edu/Profiles/Pages/Joseph-OSullivan.aspx>)

Samuel C. Sachs Professor of Electrical Engineering
PhD, University of Notre Dame
Electrical & Systems Engineering

Philip Payne (<https://publichealth.wustl.edu/scholars/philip-r-payne>)

Robert J. Terry Professor
PhD, Columbia University
Medicine; Biomedical Engineering

Jonathan E. Peelle (<http://oto.wustl.edu/About-Us/Faculty-Physicians/Jonathan-E-Peelle>)

Associate Professor of Otolaryngology
PhD, Brandeis University
Otolaryngology

David Piston (<https://pistonlab.wustl.edu>)

Professor
PhD, University of Illinois
Cell Biology & Physiology; Biomedical Engineering

Yoram Rudy (<https://engineering.wustl.edu/Profiles/Pages/Yoram-Rudy.aspx>)

Fred Saigh Distinguished Professor of Engineering
PhD, Case Western Reserve University
Biomedical Engineering

Joshua Shimony (<https://sites.wustl.edu/nillabs/people/joshua-s-shimony>)

Professor of Radiology
PhD, University of Tennessee
Department of Radiology

Koresh Shoghi (<https://www.mir.wustl.edu/research/research-laboratories/radiological-chemistry-and-imaging-laboratory-rcil/people/biotemplate-rcil/koresh-shoghi>)

Associate Professor
PhD, University of California, Los Angeles
Radiology; Biomedical Engineering

Monica Shokeen (<https://www.mir.wustl.edu/research/research-laboratories/optical-radiology-laboratory-ori/people/bio-page-template/monica-shokeen>)

Assistant Professor
PhD, Washington University
Radiology

Yuan-Chuan Tai (<https://www.mir.wustl.edu/research/research-laboratories/radiological-chemistry-and-imaging-laboratory-rcil/people/bio-template3/yuan-chuan-tai>)

Associate Professor
PhD, University of California, Los Angeles
Radiology; Biomedical Engineering

David Van Essen (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=1569)

Alumni Endowed Professor
PhD, Harvard University
Neuroscience; Biomedical Engineering

Richard Wahl (<https://wuphysicians.wustl.edu/for-patients/find-a-physician/richard-leo-wahl>)

Elizabeth E. Mallinckrodt Professor of Radiology
MD, Washington University
Radiology

Yong Wang (<https://reproductivesciences.wustl.edu/people/yong-wang>)

Assistant Professor
PhD, Washington University
Obstetrics & Gynecology; Radiology; Biomedical Engineering

Pam Woodard (<https://www.mir.wustl.edu/research/research-laboratories/cardiovascular-imaging-laboratory-cvil/people/cvil-faculty/cvil-faculty-bio-pamela-woodard>)

Professor
MD, Duke University
Radiology; Biomedical Engineering

Deshan Yang (<https://radonc.wustl.edu/faculty/deshan-yang-phd>)

Associate Professor
PhD, University of Wisconsin-Madison
Radiation Oncology; Biomedical Engineering

Tiezh Zhang (<https://radonc.wustl.edu/faculty/tiezh-zhang-phd>)

Assistant Professor
PhD, University of Wisconsin-Madison
Radiation Oncology; Biomedical Engineering

Jie Zheng (<https://www.mir.wustl.edu/research/research-laboratories/cardiovascular-imaging-laboratory-cvil/people/cvil-faculty/bio-jie-zheng>)

Associate Professor
PhD, University of Cincinnati
Radiology; Biomedical Engineering

Quing Zhu (<https://engineering.wustl.edu/Profiles/Pages/Quing-Zhu.aspx>)

Professor
PhD, University of Pennsylvania
Biomedical Engineering

Degree Requirements PhD in Imaging Science

Requirements

- Maintain an average grade of B (GPA 3.0) for all 72 units (up to 24 graduate units may be transferred with approval)
- Complete courses with no more than one grade below B-
- Complete at least one semester-long research rotation
- Become integrated with a research group
- Pass a qualifying exam
- Successfully defend a thesis proposal
- Present and successfully defend a dissertation

- Complete the mentored teaching experience required by the student's administrative home department

Courses

Required Core Courses (22 units)

- BME/CSE/ESE, Mathematics of Imaging Science (3 units)
- ESE 506, Seminar in Imaging Science and Engineering (1 unit)
- BME 593, Computational Methods for Imaging Science (3 units)
- ESE 589, Biological Imaging Technology (3 units)
- BME/ESE 5907, Theoretical Imaging Science (3 units)
- BME/CSE/ESE, Image Analysis and Data-Driven Imaging (3 units)
- BME/ESE/CSE, Practicum in Computational Imaging (3 units)
- BME 601, Research Rotation (3 units) (refer to Research Rotations (p. 66) section)

At least 12 units in elective imaging courses must be completed that span any of the following categories:

- Computational Imaging & Theory
- Imaging Sensors & Instrumentation
- Image Formation & Imaging Physics
- Translational Biomedical Imaging
- Medical Physics

Progression of Courses (Typical)

First Semester

- BME/CSE/ESE, Mathematics of Imaging Science (3 units)
- ESE 506, Seminar in Imaging Science & Engineering (1 unit)
- BME 601, Research Rotation (3 units) (refer to Research Rotations (p. 66) section)
- Elective (3 units)

Second Semester

- BME 593, Computational Methods for Imaging Science (3 units)
- ESE 589, Biological Imaging Technology (3 units)
- Elective (3 units) or optional Second Research Rotation – BME 601 (3 units)

Third Semester

- BME 5907, Theoretical Imaging Science (3 units)
- BME/CSE/ESE, Image Analysis & Data-Driven Imaging (3 units)
- Elective (3 units)

Fourth Semester

- BME/ESE/CSE, Practicum in Computational Imaging (3 units)
- Elective or doctoral research (3 units)
- Elective or doctoral research (3 units)

Electives Courses — Computational Imaging & Theory

- BME/ESE, Adaptive Imaging
- BME/ESE, Wave Physics and Applied Optics for Imaging Scientists
- CSE 501N, Programming Concepts and Practice
- CSE 512A, Statistical Computing for Scientific Research
- CSE 511A, Introduction to Artificial Intelligence
- CSE 513T, Theory of Artificial Intelligence & Machine Learning
- CSE 515T, Bayesian Methods in Machine Learning
- CSE 517A, Machine Learning
- CSE 519T, Advanced Machine Learning
- CSE 543T, Algorithms for Nonlinear Optimization
- CSE 546T, Computational Geometry
- CSE 554A, Geometric Computing for Biomedicine
- CSE 555A, Computational Photography
- CSE 559A, Computer Vision
- CSE 566S, High Performance Computer Systems
- ESE 523, Information Theory
- ESE 588, Quantitative Image Processing
- ESE 524, Detection and Estimation Theory
- ESE 518, Optimization Methods in Control

Electives Courses — Imaging Sensors & Instrumentation

- CSE 568M, Imaging Sensors
- BME, Imaging Instrumentation

Electives Courses — Image Formation & Imaging Physics

- BME 591, Biomedical Optics I
- BME 592, Biomedical Optics II
- BME 494, Ultrasound Imaging
- BME 5XX, Advanced Topics in Ultrasound Imaging (To be developed)
- BME 5XX, Magnetic Resonance Imaging (To be developed)
- BME 5XX, Imaging in Nuclear Medicine (To be developed)
- ESE 582/BME 5820 Fundamentals and Applications of Modern Optical Imaging

Electives Courses — Translational Biomedical Imaging

- BME, Therapeutic Applications of Biomedical Imaging
- BME 502, Cardiovascular MRI-Physics to Clinical Application

Electives Courses — Medical Physics

- BME 5071, Radiobiology
- BME 5072, Radiation Oncology Physics
- BME 507, Radiological Physics and Dosimetry
- BME 5073, Radiation Protection and Safety

Approved Life Science Courses

- BME 530A Molecular Cell Biology for Engineers
- BME 503A Cell & Organ Systems
- BME 538 Cell Signal Transduction
- BME 5902 Cellular Neurophysiology
- Biol 4071 Developmental Biology
- Biol 4580 Principles of Human Anatomy & Development
- Biol 4810 General Biochemistry
- Biol 4820 General Biochemistry II
- Biol 5068 Fundamentals of Molecular Cell Biology
- Biol 5319 Molecular Foundations of Medicine
- Biol 5051 Foundations in Immunology (4 units)
- Biol 5053 Immunobiology (4 units)
- Biol 5062 Central Questions in Cell Biology
- Biol 5146 Principles and Applications of Biological Imaging
- Biol/Chem 5147 Contrast Agents for Biological Imaging
- Biol 5224 Molecular, Cell, and Organ Systems
- Biol 5285 Fundamentals of Mammalian Genetics
- Biol 5352 Developmental Biology
- Biol 5488 Genomics
- Biol 5571 Cellular Neurobiology (4 units)
- Biol 5651 Neural Systems
- Biol 5581 Neural Basis of Acoustic Communication
- Biol 404 Laboratory of Neurophysiology
- Biol 548 Nucleic Acids and Protein Biosynthesis
- Biol 5663 Neurobiology of Disease

Approved Mathematics Courses — Any graduate-level course within the Department of Mathematics and Statistics is approved.

Research Rotations

During their first year, students are required to register for and complete at least one research rotation (for 3 units) with program faculty mentors. The research rotation(s) allow students to sample different research projects and laboratory working environments before selecting the group in which they will carry out the PhD dissertation research.

A rotation will be chosen in consultation with program faculty and must be mutually agreeable to both the student and the mentor. At the completion of each rotation, the student must submit to the mentor and director a written report approved by the mentor.

Qualifying Exam

A written qualifying exam will be administered during the *spring* of their second year of graduate school. The examining

committee, who will develop and grade the exams, will consist of three members of the Imaging Science PhD Program Committee. The director of the graduate program will approve the committee, whose members will be suggested by the thesis adviser.

Students will choose three out of the four exam topics:

- Mathematics of Imaging Science
- Imaging Physics & Image Formation Methods
- Image Analysis & Data-Driven Imaging
- Theoretical Image Science

Finding a Thesis Research Mentor

Because the PhD is a research degree, the student is expected to become integrated within a research group. By the end of the first year of study, students should have found a thesis adviser who will oversee their PhD research and assume financial responsibility for stipend, tuition, health insurance, and student fees. The thesis adviser must be a faculty member in the Imaging Science PhD Program Committee with the title of professor, associate professor, or assistant professor. Failure to find a research adviser by May 1 will result in the student being placed on probation that can last up until August 31. During that time, the student must continue to seek a research adviser. Failure to find a research adviser by August 31 will lead to dismissal from the PhD program and termination of funding.

The student's admission application should include transcripts and letters of evaluation. The Graduate Admissions Committee will review all applications and construct a ranked list of candidates. This list and the associated application packages will be forwarded to the dean of the Graduate School for approval for admission to the program. Following approval by the dean of the Graduate School and the director of the graduate program, the chair of the Graduate Admissions Committee will notify the students accepted by letter.

Research Presentation/Thesis Proposal

Before the end of the student's third year, the student will give an oral presentation of their proposed PhD project, with the necessary background to support it, to the Thesis Committee. This committee will consist of six members. Four members must be members of the Imaging Science PhD Program Committee. At least one committee member must be chosen from outside the Imaging Science PhD Program Committee, and must be a tenured or tenure-track faculty member at Washington University. The committee will be chaired by the PhD mentor. At least two weeks prior to the presentation, the student will present to the Thesis Examination Committee a written document outlining the research background, proposed procedures, preliminary results, and plans for completion. The required document will be typically between 15 and 30 pages in length and must contain a comprehensive bibliography.

The student will be placed on probation if they fail to pass their Thesis Proposal by the sixth semester. The student will be given a second opportunity to pass the exam during their seventh semester. If the student passes the second exam and meets the other program requirements (e.g., grades), they may continue the program without prejudice. If the student fails the exam a second time, they will be terminated from the PhD program.

Dissertation

The student will prepare a written dissertation for examination by the Thesis Examination Committee and will defend the dissertation before this committee. Should a member of this committee be unable to participate, the director of the graduate program, in consultation with the PhD mentor, will choose a replacement. If the committee members feel that the dissertation has deficiencies, they may recommend that the candidate address them and send the revised dissertation to the committee members for approval. The committee may also recommend that the candidate present another oral defense of the modified work. The Thesis Committee will inform the director of the graduate program, and they will warn the student in writing that they must submit a revised dissertation and pass the oral defense (if recommended) in order to complete the PhD program. If, after revision and reexamination, the Thesis Committee still finds deficiencies and cannot reach unanimous agreement to approve the dissertation, the Graduate School's Policy on Dissenting Votes will apply.

Teaching Requirements

Students in the PhD program will receive formal pedagogical training by attending a minimum of two Teaching Workshops offered by the Washington University Teaching Center (<http://teachingcenter.wustl.edu/graduate-students/workshops>). They will be expected to fulfill the teaching requirements of their designated administrative home department. The teaching requirements must be completed before the student submits their doctoral dissertation to the Graduate School.

Courses

For information regarding courses, please refer to the Degree Requirements (p. 64) section of this page.

Materials Science & Engineering

The Institute of Materials Science & Engineering (IMSE) at Washington University in St. Louis offers a unique, interdisciplinary PhD in Materials Science & Engineering that crosses traditional departmental and school boundaries. The field of materials science and engineering focuses on the study, development and application of new materials with desirable properties, with the goal of enabling new products and superior performance regimes. Disciplines in the physical sciences (chemistry, physics, etc.) frequently play a central role in

developing the fundamental knowledge that is needed to design materials for a variety of engineering applications (mechanical engineering, electrical engineering, chemical engineering, etc.). Building on training that spans from fundamental-to-applied sciences, materials scientists and engineers integrate this fundamental knowledge in order to develop new materials and match them with appropriate technological needs.

The IMSE is well positioned to address the needs of a student seeking a truly interdisciplinary experience. Established in 2013, the IMSE brings together a diverse group of faculty from departments in Arts & Sciences, the School of Engineering & Applied Science, and the School of Medicine. The IMSE integrates and expands the existing materials activities at Washington University by overseeing shared research and instrument facilities, creating partnerships with industry and national facilities, and setting up outreach activities.

Current focused areas of research and advanced graduate education within the IMSE include:

Biomedical, Bio-derived, and Bio-inspired Materials

Materials for Energy Generation, Harvesting, and Storage

Materials for Environmental Technologies & Sustainability

Nanomaterials and Glasses

Materials for Sensors and Imaging

Thin Film & 2D Materials

Contact: Beth Gartin
Phone: 314-935-7191
Email: bgartin@wustl.edu
Website: <http://imse.wustl.edu>

Faculty

Director

Katharine M. Flores (<https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx>)
Professor - Mechanical Engineering & Materials Science
PhD, Stanford University
Professor Flores' primary research interest is the mechanical behavior of structural materials, with particular emphasis on understanding structure-processing-property relationships in bulk metallic glasses and their composites.

Professors

Richard Axelbaum (<https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx>)

The Stifel & Quinette Jens Professor of Environmental Engineering Science

PhD, University of California, Davis

Rich Axelbaum studies combustion phenomena, ranging from oxy-coal combustion to flame synthesis of nanotubes. His studies of fossil fuel combustion focus on understanding the formation of pollutants, such as soot, and then using this understanding to develop novel approaches to eliminating them. Recently, his efforts have been focused on addressing global concerns over carbon dioxide emissions by developing approaches to carbon capture and storage (CCS).

Pratim Biswas (<https://engineering.wustl.edu/Profiles/Pages/Pratim-Biswas.aspx>)

Lucy & Stanley Lopata Professor & Department Chair - Energy, Environmental & Chemical Engineering

PhD, California Institute of Technology

Professor Biswas's research interests include aerosol science and engineering; nanoparticle technology; air quality engineering; environmentally benign energy production; combustion; materials processing for environmental technologies, environmentally benign processing, environmental nanotechnology, and the thermal sciences.

William Buhro (<http://chemistry.wustl.edu/faculty/buhro>)

George E. Pake Professor in Arts & Sciences and Department Chair - Chemistry

PhD, University of California, Los Angeles

Synthetic inorganic and materials chemistry; optical properties of semiconductor nanocrystals, including quantum wires, belts and platelets; metallic nanoparticles; magic-size nanoclusters; nanoparticle growth mechanisms; and charge and energy transport in nanowires.

Shantanu Chakrabartty (<https://engineering.wustl.edu/Profiles/Pages/Shantanu-Chakrabartty.aspx>)

Professor - Electrical & Systems Engineering

PhD, Johns Hopkins University

Shantanu Chakrabartty's research explores new frontiers in unconventional analog computing techniques using silicon and hybrid substrates. His objective is to approach fundamental limits of energy efficiency, sensing and resolution by exploiting computational and adaptation primitives inherent in the physics of devices, sensors and the underlying noise processes. Professor Chakrabartty is using these novel techniques to design self-powered computing devices, analog processors and instrumentation with applications in biomedical and structural engineering.

Sophia E. Hayes (<http://www.chemistry.wustl.edu/people/primary-faculty/sophia-e-hayes>)

Professor - Chemistry

PhD, University of California, Santa Barbara

Physical inorganic chemistry; materials chemistry; solid-state NMR; magnetic resonance; optically-pumped NMR (OPNMR); semiconductors; quantum wells; magneto-optical spectroscopy; quadrupolar NMR of thin films and tridecameric metal hydroxide clusters and thin films; carbon capture, utilization and storage (CCUS); CO₂ geosequestration; CO₂ capture; in situ NMR; metal carbonate formation.

Kenneth F. Kelton (http://www.physics.wustl.edu/people/kelton_kenneth-f)

Arthur Holly Compton Professor of Arts & Sciences - Physics
PhD, Harvard University

Study and production of titanium-based quasicrystals and related phases. Fundamental investigations of time-dependent nucleation processes. Modeling of oxygen precipitation in single crystal silicon. Structure of amorphous materials. Relation between structure and nucleation barrier. Hydrogen storage in quasicrystals.

Vijay Ramani (<https://engineering.wustl.edu/Profiles/Pages/Vijay-Ramani.aspx>)

Roma B. & Raymond H. Wittcoff Distinguished University Professor of Environment & Energy

PhD, University of Connecticut

Vijay Ramani's research interests lie at the confluence of electrochemical engineering, materials science and renewable and sustainable energy technologies. The National Science Foundation, Office of Naval Research and Department of Energy have funded his research, with mechanisms including an NSF CAREER award (2009) and an ONR Young Investigator Award (ONR-YIP; 2010).

Lan Yang (<https://engineering.wustl.edu/Profiles/Pages/Lan-Yang.aspx>)

Edwin H. & Florence G. Skinner Professor - Electrical & Systems Engineering

PhD, California Institute of Technology

Professor Yang's research interests are fabrication, characterization, and fundamental understanding of advanced nano/micro photonic devices with outstanding optical properties. Currently, her group focuses on the silicon-chip based ultra-high-quality micro-resonators made from spin-on glass. The spin-on glass is a kind of glass obtained by curing a special liquid using sol gel or wet chemical synthesis to form a layer of glass. The main advantage of the spin-on glass is the easy tailoring of the nano/micro structure of the glass by controlled variation in the precursor solutions. It enables them to fabricate various micro/nano photonic devices from advanced materials with desired properties.

Associate Professors

John Fortner (<https://engineering.wustl.edu/Profiles/Pages/John-Fortner.aspx>)

I-CARES Career Development Associate Professor - Energy, Environmental & Chemical Engineering
PhD, Rice University

John Fortner's research is primarily focused on advancing water-related technologies and engineering novel material interfaces as they relate to critical environmental-based health, security and energy challenges. He has extensively studied the environmental fate, (photo) reactivity and applications (e.g., novel water treatment membranes) of engineered carbon nanomaterials, including fullerenes, carbon nanotubes, and graphene-based materials.

Harold Li (<https://radonc.wustl.edu/faculty/harold-li>)

PhD, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Associate Professor - Radiation Oncology

Harold Li's research lab, funded by the NIH since 2008, develops high resolution dosimetry systems for radiation therapy dosimetry. In addition, he leads the MRgRT group in developing both experimental and computational methods for radiation therapy patient dosimetry subject to a permanent magnetic field.

Srikanth Singamaneni (<https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx>)

Associate Professor - Mechanical Engineering & Materials Science

PhD, Georgia Institute of Technology

Professor Singamaneni's research interests include plasmonic engineering in nanomedicine (in vitro biosensing for point-of-care diagnostics, molecular bioimaging, nanotherapeutics), photovoltaics (plasmonically enhanced photovoltaic devices), surface enhanced Raman scattering (SERS) based chemical sensors with particular emphasis on the design and fabrication of unconventional and highly efficient SERS substrates, hierarchical organic/inorganic nanohybrids as multifunctional materials, bioinspired structural and functional materials, polymer surfaces and interfaces, responsive and adaptive materials and scanning probe microscopy and surface force spectroscopy of soft and biological materials.

Philip Skemer (http://eps.wustl.edu/people/phil_skemer)

Associate Professor - Earth and Planetary Sciences

Professor Skemer's research interests include mantle deformation, the formation and the dynamics of plate boundaries, and the interpretation of seismological data. The underlying motivation for his research is to understand the remarkable phenomenon of plate tectonics and its variability among the terrestrial planets. Although primarily an experimentalist, his research uses the microstructures of naturally deformed rocks to infer the importance of specific deformation processes in Earth, and then develops experiments to investigate the sensitivity of these processes to a range of deformation conditions. From these experiments, one can make predictions about rock deformation at conditions or locations that are inaccessible to direct observation.

Assistant Professors

Damena Agonafer (<https://engineering.wustl.edu/Profiles/Pages/Damena-Agonafer.aspx>)

Assistant Professor - Mechanical Engineering & Materials Science

PhD, University of Illinois

Professor Agonafer's research interest includes the areas of phase routing strategies for chemical separation and phase change heat transfer processes, and electrochemical storage applications. His research interest is at the intersection of thermal-fluid sciences, electrokinetics and interfacial transport phenomena, and renewable energy. His goal is to bring transformational changes in the areas related to electrochemical energy storage, cooling of high powered micro and power electronics, and water desalination by tuning and controlling solid-liquid-vapor interactions at micro/nano length scales.

Anupriya Agrawal (<https://mems.wustl.edu/faculty/Pages/Anupriya-Agrawal.aspx>)

Research Assistant Professor - Mechanical Engineering & Materials Science

PhD, Ohio State University

Professor Agrawal's research focuses on investigating the structure and dynamics of polymers and metallic glasses using molecular dynamics simulations. She is interested in investigating the deformation behavior of metallic glasses and composites. Her interest also lies in exploring polymer properties such as deformation behavior, diffusion of small organic molecules and ionic aggregation at large length and time scales using multi-scale models.

Peng Bai (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=122>)

Assistant Professor - Energy, Environmental & Chemical Engineering

PhD, Tsinghua University, Beijing

Professor Bai's research focuses on the development of next-generation batteries. Knowledge and tools developed in the Bai Group also apply to and benefit the design of other electrochemical energy systems like supercapacitors and fuel cells.

Alexander Barnes (<http://chemistry.wustl.edu/faculty/barnes>)
Assistant Professor - Chemistry

PhD, Massachusetts Institute of Technology

Magnetic resonance; dynamic nuclear polarization; structural biology; rational drug design; HIV eradication; Alzheimer's; cancer; electrical engineering; gyrotron technology; molecular biology; biophysical chemistry.

Mikhail Y. Berezin (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=6263)

Assistant Professor - Radiology

PhD, Moscow Institute of Oil and Gas/Institute of Organic Chemistry

Professor Berezin's research interest lies in the investigation and application of molecular excited states and their reactions for medical imaging and clinical treatment. Excited states are the cornerstone of a variety of chemical, physical, and biological phenomena. The ability to probe, investigate, and control excited states is one of the largest achievements of modern science. The lab focuses on the development of novel optically active probes ranging from small molecules to nanoparticles, and the development of optical instrumentation for spectroscopy and imaging and their applications in medicine.

Rajan Chakrabarty (<https://engineering.wustl.edu/Profiles/Pages/Rajan-Chakrabarty.aspx>)

Assistant Professor - Energy, Environmental & Chemical Engineering

PhD, University of Nevada, Reno

Rajan Chakrabarty's research focuses on two distinct themes: (i) Investigating the role of atmospheric aerosols in earth's energy balance using novel instrumentation and diagnostic techniques, and numerical models; and (ii) Understanding aerosol formation in combustion systems toward synthesis of high porosity and surface-area materials for energy applications.

Julio D'Arcy (<http://www.chemistry.wustl.edu/faculty/darcy>)

Assistant Professor - Chemistry

PhD, University of California, Los Angeles

The overarching goals of the D'Arcy laboratory are to discover and apply novel functional nanostructured organic and inorganic materials utilizing universal synthetic chemistry protocols that control chemical structure, nanoscale morphology, and intrinsic properties. We are interested in capacitive and pseudocapacitive nanostructured materials such as conducting polymers, metal oxides, and carbon allotropes possessing enhanced chemical and physical properties, i.e., charge carrier transport, ion transport, surface area, thermal and mechanical stability. Our concerted material discovery process is a multipronged approach; organic and inorganic nanostructured materials are synthesized via solution processing, electrochemistry, vapor phase deposition, and combinations thereof. Alternatively, we also develop self-assembly techniques that result in tailored materials.

Marcus Foston (<https://engineering.wustl.edu/Profiles/Pages/Marcus-Foston.aspx>)

Assistant Professor - Energy, Environmental & Chemical Engineering

PhD, Georgia Institute of Technology

Professor Foston's research objective is to create a top tier, world-recognized research program in the research and education of emerging technologies for exploitation of lignocellulosic biomass, in particular the lignin fraction of biomass, as a sustainable source for energy, chemicals and materials production.

Erik Henriksen (https://www.physics.wustl.edu/people/henriksen_erik)

Assistant Professor - Physics

PhD, Columbia University

We are an experimental condensed matter research lab with interests primarily in the quantum electronic properties of graphene and other novel two-dimensional systems. We utilize state-of-the-art nanofabrication techniques in combination with measurements made at low temperatures and high magnetic fields to explore both the fundamental electronic structures and emergent quantum phenomena of low-dimensional materials.

Mark Meacham (<https://engineering.wustl.edu/Profiles/Pages/Mark-Meacham.aspx>)

Assistant Professor - Mechanical Engineering & Materials Science

PhD, Georgia Institute of Technology

Mark Meacham's research interests include microfluidics, micro-electromechanical systems (MEMS) and associated transport phenomena, with application to design, development and testing of novel energy systems and life sciences tools, from scalable micro-/nanotechnologies for improved heat and mass exchangers to MEMS-based tools for manipulation and investigation of cellular processes. He is also interested in the behavior of jets and/or droplets of complex fluids during ejection from microscopic orifices, which is critical to applications as disparate as biological sample preparation and additive manufacturing.

Rohan Mishra (<https://engineering.wustl.edu/Profiles/Pages/Rohan-Mishra.aspx>)

Assistant Professor - Mechanical Engineering & Materials Science

PhD, Ohio State University

In his lab at Washington University, Mishra plans to identify and develop a quantitative measure of structure-property correlations in materials, such as epitaxial thin films and materials with reduced dimensionality, using a synergistic combination of scanning transmission electron microscopy and atomic-scale theory, to create rational design of materials with properties tailored for electronic, magnetic, optical and energy applications.

Ryan Ogiore (http://physics.wustl.edu/people/ogiore_ryan)

Assistant Professor - Physics

PhD, California Institute of Technology

Professor Ogiore's research group uses microanalytical techniques to study extraterrestrial materials in order to better understand the formation and evolution of our solar system, as well as other stars.

Bryce Sadtler (<http://www.chemistry.wustl.edu/faculty/sadtler>)

Assistant Professor - Chemistry

PhD, University of California, Berkeley

The Sadtler research group seeks to understand and control structure-property relationships in adaptive, mesostructured materials. Through hierarchical design of the atomic composition, nanoscale morphology, and mesoscale organization of the individual components, we can direct the emergent chemical reactivity and physical properties of these complex systems. Research projects combine solution phase growth techniques to synthesize inorganic materials, external fields to control the growth and assembly of mesoscale architectures, and super-resolution imaging to provide spatiotemporal maps of the optical response and photocatalytic activity during the morphological evolution of these structures. Knowledge gained from these fundamental studies will be used to create functional materials, including plasmonic substrates that enhance absorption in thin-film semiconductors, mesostructured photocatalysts for solar fuels generation, and chemical sensors based on self-assembled photonic structures.

Simon Tang (<http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx>)

Assistant Professor - Orthopaedics

PhD, Rensselaer Polytechnic Institute

With the overall theme of understanding the biological regulation of skeletal matrix quality, our research group integrates engineering and biology approaches for (1) understanding the effect of disease mechanisms on the structure-function relationships of skeletal tissues and (2) developing of translatable therapeutic and regenerative strategies for these diseases. The investigation of these scientific questions includes the application of finite element analyses, multiscale tissue mechanics, and the functional imaging of skeletal tissues for regenerative medicine with in vitro and in vivo biological systems.

Elijah Thimsen (<https://engineering.wustl.edu/Profiles/Pages/Elijah-Thimsen.aspx>)

Assistant Professor - Energy, Environmental & Chemical Engineering

PhD, Washington University

The Interface Research Group focuses on advanced gas-phase synthesis of nanomaterials for energy applications. We are currently exploring nonthermal plasma synthesis and atomic layer deposition (ALD). The goal is to discover and then understand useful interfacial phenomena. Examples of applications we are currently interested in are: transparent conducting oxides, photovoltaics, lithium-sulfur batteries, and coatings for high-temperature combustion.

Patricia Weisensee (<https://mems.wustl.edu/faculty/Pages/default.aspx?bio=112>)

Assistant Professor - Mechanical Engineering & Materials Science

PhD, University of Illinois at Urbana-Champaign

Patricia Weisensee's work focuses on the interaction of liquids and micro- and nanostructured solids. Her research is both fundamental and applied and spans a wide range of applications in the fluid and thermal sciences, from droplet impact over phase change heat transfer to electronics cooling.

Degree Requirements

Interdisciplinary PhD in Materials Science & Engineering

To earn a PhD degree, students must complete the Graduate School requirements, along with specific program requirements.

Courses include:

- Four IMSE Core Courses (12 academic credits)

Code	Title	Units
MEMS 5608	Introduction to Polymer Science and Engineering	3
Physics 537	Kinetics of Materials	3
EECE 502	Advanced Thermodynamics in EECE	3
Chem 465 or Physics 472	Solid-State and Materials Chemistry Solid State Physics	3
Total Units		12

- IMSE 500 First-Year Research Rotation (3 academic credits)
- Three courses (9 credits) from a preapproved list of Materials Science & Engineering electives
- A minimum of 12 credits of graduate-level technical elective courses in Mathematics or any science or engineering department, to reach a total of at least 36 academic credits
 - A maximum of 3 credits of IMSE 502 Independent Study will be permitted toward the free electives requirement.
 - A maximum of 3 credits of IMSE 505 Material Science Journal Club will be permitted toward this requirement.
 - 400-level courses not included on the preapproved list of Materials Science & Engineering electives must be approved by the Graduate Studies Committee.
- A maximum of 12 credits of 400-level courses may be applied to the required 36 academic credits. Undergraduate-only courses (below the 400 level) are generally not permitted by the Graduate School and may not be used to fulfill this requirement.
- Enroll in and satisfactorily complete IMSE 501 IMSE Graduate Seminar every semester
- Successfully complete 18-36 credits of IMSE 600 Doctoral Research

- Complete research ethics training by the end of the third semester
- Maintain a GPA of at least 3.0 for all graded courses
 - Have no more than one grade of B- or below in a core course or Materials Science & Engineering elective
- Successfully complete teaching requirement
 - Attend 2+ Teaching Center Workshops
 - Have 15 units of teaching experience
- Pass the IMSE Qualifying Examination (oral & written)
- Identify an IMSE faculty member willing and able to support their thesis research on a materials-related topic
- Maintain satisfactory research progress on a topic in materials science, as determined by the thesis adviser and Mentoring Committee
- Successfully complete the Thesis Proposal and Presentation, with approval from the Thesis Examination Committee
- Successfully complete and defend a PhD Dissertation, with final approval from the Thesis Examination Committee

Failure to meet these requirements will result in dismissal from the program.

Course Plan

Year 1

Fall Semester (13 credits)

- Solid-State and Materials Chemistry (Chem 465) or Elective
- Advanced Thermodynamics in EECE (EECE 502)
- Introduction to Polymer Science and Engineering (MEMS 5608)
- Elective (optional)
- IMSE Graduate Seminar (IMSE 501)

Spring Semester (13 credits)

- Solid State Physics (Physics 472) or Elective
- Kinetics of Materials (Physics 537)
- Elective (optional)
- IMSE First-Year Research Rotation (IMSE 500)
- IMSE Graduate Seminar (IMSE 501)

Summer

- Begin thesis research
- Prepare for Qualifying Exam (August)
 - Written document and oral presentation on research rotation
 - Oral exam on fundamentals from core courses

Years 2 and beyond

- Electives (discuss with PhD adviser)
- IMSE Graduate Seminar (IMSE 501)

- Doctoral Research (IMSE 600)
- Teaching Requirement
 - Attend 2+ Teaching Center Workshops
 - 15 units of Mentored Teaching Experience
- Annual (or more frequent) meetings with Faculty Mentoring Committee
- Thesis proposal and presentation (fifth semester)
- Dissertation and oral defense

Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science offers a **PhD** and **DSc** in either **Mechanical Engineering** or **Aerospace Engineering** along with a **DSc in Materials Science**. The department's research strengths include biomechanics, materials, energy, fluid mechanics, and rotary-wing aerodynamics. The doctoral student works in conjunction with their adviser in designing the program of study and research project. The dissertation is defended at the end of the research effort. A typical time to PhD after an undergraduate engineering degree is four to five years, but the length of program may vary, depending on the individual and the area of study.

The Department of Mechanical Engineering & Materials Science offers an **MS** degree in either **Mechanical Engineering**, **Aerospace Engineering**, or **Materials Science and Engineering**. The department also offers a **Master of Engineering in Mechanical Engineering** for those coming from fields closely related to mechanical engineering. The MS degrees can be done either as a course option or a thesis option. For the thesis option, the student will work closely with a faculty adviser on the thesis project. Typical time for an MS or MEng degree is one and one-half to two years, with the thesis option usually taking longer than the course option.

Faculty contact for the PhD program: Jessica Wagenseil (<https://engineering.wustl.edu/Profiles/Pages/Jessica-Wagenseil.aspx>)

Faculty contact for the MS and DSc programs: David Peters (<https://mems.wustl.edu/faculty/Pages/default.aspx?bio=92>)

Faculty contact for the MS in Materials Science & Engineering: Katharine Flores (<https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx>)

Website: <https://mems.wustl.edu/graduate/programs>

Faculty

Chair

Philip V. Bayly (<https://engineering.wustl.edu/Profiles/Pages/Philip-Bayly.aspx>)
Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Duke University
Nonlinear dynamics, vibrations, biomechanics

Associate Chairs

Katharine M. Flores (Materials Science) (<https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx>)
PhD, Stanford University
Mechanical behavior of structural materials

David A. Peters (Mechanical Engineering) (<https://mems.wustl.edu/faculty/Pages/default.aspx?bio=92>)
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics

Endowed Professors

Ramesh K. Agarwal (<https://engineering.wustl.edu/Profiles/Pages/Ramesh-Agarwal.aspx>)
William Palm Professor of Engineering
PhD, Stanford University
Computational fluid dynamics and computational physics

Guy M. Genin (<https://engineering.wustl.edu/Profiles/Pages/Guy-Genin.aspx>)
Harold & Kathleen Faught Professor of Mechanical Engineering
PhD, Harvard University
Solid mechanics, fracture mechanics

Mark J. Jakiela (<https://engineering.wustl.edu/Profiles/Pages/Mark-Jakiela.aspx>)
Lee Hunter Professor of Mechanical Design
PhD, University of Michigan
Mechanical design, design for manufacturing, optimization, evolutionary computation

Shankar M.L. Sastry (<https://engineering.wustl.edu/Profiles/Pages/Shankar-Sastry.aspx>)
Christopher I. Byrnes Professor of Engineering
PhD, University of Toronto
Materials science, physical metallurgy

Professors

Jianjun Guan (<https://engineering.wustl.edu/Profiles/Pages/Jianjun-Guan.aspx>)
PhD, Zhejiang University
Biomimetic biomaterials synthesis and scaffold fabrication

Srikanth Singamaneni (<https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx>)
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Associate Professors

Spencer P. Lake (<https://engineering.wustl.edu/Profiles/Pages/Spencer-Lake.aspx>)
PhD, University of Pennsylvania
Soft tissue biomechanics

Jessica E. Wagenseil (<https://engineering.wustl.edu/Profiles/Pages/Jessica-Wagenseil.aspx>)
DSc, Washington University
Arterial biomechanics

Assistant Professors

Damena D. Agonafer (<https://mems.wustl.edu/faculty/Pages/default.aspx?bio=110>)
PhD, University of Illinois at Urbana-Champaign
Computational fluid dynamics and computational physics

J. Mark Meacham (<https://engineering.wustl.edu/Profiles/Pages/Mark-Meacham.aspx>)
PhD, Georgia Institute of Technology
Micro-/Nanotechnologies for thermal systems and the life sciences

Rohan Mishra (<https://engineering.wustl.edu/Profiles/Pages/Rohan-Mishra.aspx>)
PhD, Ohio State University
Computational materials science

Amit Pathak (<https://engineering.wustl.edu/Profiles/Pages/Amit-Pathak.aspx>)
PhD, University of California, Santa Barbara
Cellular biomechanics

Patricia B. Weisensee (<https://mems.wustl.edu/faculty/Pages/default.aspx?bio=112>)
PhD, University of Illinois at Urbana-Champaign
Thermal fluids

Professors of the Practice

Harold J. Brandon
DSc, Washington University
Energetics, thermal systems

Swami Karunamoorthy (<https://mems.wustl.edu/faculty/Pages/Swami-Karunamoorthy.aspx>)
DSc, Washington University
Helicopter dynamics, engineering education

Teaching Professor

Emily J. Boyd (<https://engineering.wustl.edu/Profiles/Pages/Emily-Boyd.aspx>)
PhD, University of Texas at Austin
Thermofluids

Joint Faculty

Richard L. Axelbaum (EECE) (<https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx>)
Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Combustion, nanomaterials

Elliot L. Elson (Biochemistry and Molecular Biophysics) (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=188)
Professor Emeritus of Biochemistry & Molecular Biophysics
PhD, Stanford University
Biochemistry and molecular biophysics

Michael D. Harris (Physical Therapy, Orthopaedic Surgery and MEMS) (<https://pt.wustl.edu/faculty-staff/faculty/mike-harris-phd>)
PhD, University of Utah
Whole body and joint-level orthopaedic biomechanics

Kenneth F. Kelton (Physics) (http://www.physics.wustl.edu/people/kelton_kenneth-f)
Arthur Holly Compton Professor of Arts & Sciences
PhD, Harvard University
Study and production of titanium-based quasicrystals and related phases

Eric C. Leuthardt (Neurological Surgery and BME) (<http://www.neurosurgery.wustl.edu/patient-care/find-a-physician/clinical-faculty/eric-c-leuthardt-md-250>)
MD, University of Pennsylvania School of Medicine
Neurological surgery

Lori Setton (BME) (<https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=105>)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomechanics for local drug delivery: tissue regenerations specific to the knee joints and spine

Matthew J. Silva (Orthopaedic Surgery) (<http://www.orthoresearch.wustl.edu/content/Laboratories/2963/Matthew-Silva/Silva-Lab/Overview.aspx>)
Julia and Walter R. Peterson Orthopaedic Research Professor
PhD, Massachusetts Institute of Technology
Biomechanics of age-related fractures and osteoporosis

Simon Tang (Orthopaedic Surgery, BME) (<http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx>)
PhD, Rensselaer Polytechnic Institute
Biological mechanisms

Senior Professors

Phillip L. Gould
PhD, Northwestern University
Structural analysis and design, shell analysis and design, biomechanical engineering

Kenneth L. Jerina
DSc, Washington University
Materials, design, solid mechanics, fatigue and fracture

Salvatore P. Suter
PhD, California Institute of Technology
Viscous flow, biorheology

Barna A. Szabo
PhD, State University of New York–Buffalo
Numerical simulation of mechanical systems, finite-element methods

Lecturers

J. Jackson Potter
PhD, Georgia Institute of Technology
Senior design

H. Shaun Sellers
PhD, Johns Hopkins University
Mechanics and materials

Louis G. Woodhams
BS, University of Missouri-St. Louis
Computer-aided design

Senior Research Associate

Ruth J. Okamoto
DSc, Washington University
Biomechanics, solid mechanics

Research Assistant Professor

Anupriya Agrawal
PhD, Ohio State University
Materials science

Adjunct Instructors

Ricardo L. Actis
DSc, Washington University
Finite element analysis, numerical simulation, aircraft structures

Robert G. Becnel
MS, Washington University
FE Review

John D. Biggs
MEng, Washington University
Thermal science

Andrew W. Cary
PhD, University of Michigan
Computational fluid dynamics

Dan E. Driemeyer
PhD, University of Illinois
Thermoscience

Richard S. Dyer
PhD, Washington University
Propulsion, thermodynamics, fluids

John M. Griffith
BS, Washington University
Manufacturing

Jason Hawks
MS, Washington University
Structural analysis

Richard R. Janis
MS, Washington University
Building environmental systems

Rigoberto Perez
PhD, Purdue University
Fatigue and fracture

Dale M. Pitt
DSc, Washington University
Aeroelasticity

Gary D. Renieri
PhD, Virginia Polytechnic Institute and State University
Structural applications, composite materials

Hiroshi Tada
PhD, Lehigh University
Solid mechanics

Matthew J. Watkins
MS, Washington University
Finite elements

Michael C. Wendl
DSc, Washington University
Mathematical theory and computational methods in biology and engineering

Laboratory and Design Specialist

Chiamaka Asinugo
MS, Washington University
Mechanical Engr. design

Professor Emeritus

Wallace B. Diboll Jr.

MSME, Rensselaer Polytechnic Institute
Dynamics, vibrations, engineering design

Degree Requirements

Please visit the following pages for information about

- Doctoral Degrees (p. 81)
- Master of Science in Mechanical Engineering (MSME) (p. 82)
- Master of Science in Aerospace Engineering (MSAE) (p. 83)
- Master of Science (MS) in Materials Science and Engineering (p. 83)
- Master of Engineering (MEng) in Mechanical Engineering (p. 84)

Courses

Visit online course listings to view semester offerings for E37 MEMS (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E37&crslvl=5:8>).

E37 MEMS 500 Independent Study

Independent investigation on topic of special interest. Prerequisites: graduate standing and permission of the department chair. Students must complete the Independent Study Approval Form available in the department office. Credit variable, maximum 6 units.

E37 MEMS 5001 Optimization Methods in Engineering

Analytical methods in design. Topics include: mathematical methods; linear and nonlinear programming; optimality criteria; fully stressed techniques for the design of structures and machine components; topological optimization; search techniques; and genetic algorithms. Prerequisites: calculus and computer programming. Credit 3 units. EN: TU

E37 MEMS 501 Graduate Seminar

This is a required pass/fail course for master's and doctoral degrees. A passing grade is required for each semester of full-time enrollment. A passing grade is received by attendance at the weekly seminars.

E37 MEMS 5102 Materials Selection in Design

Analysis of the scientific bases of material behavior in the light of research contributions of the past 20 years. Development of a rational approach to the selection of materials to meet a wide range of design requirements for conventional and advanced applications. Although emphasis is placed on mechanical properties, acoustical, optical, thermal and other properties of interest in design are discussed. Credit 3 units. EN: TU

E37 MEMS 5104 CAE-Driven Mechanical Design

An introduction to the use of computer-aided engineering (CAE) tools in the mechanical design process. Topics include: integrating engineering analysis throughout the process; multidisciplinary optimization; and computer-aided design directed toward new manufacturing processes. Students will work with commercial and research software systems to complete several projects. Students should have experience and familiarity with a CAD tool, optimization and the finite element method. Prerequisite: MEMS 202 Computer-Aided Design or equivalent. Credit 3 units. EN: TU

E37 MEMS 5301 Nonlinear Vibrations

In this course, students are introduced to concepts in nonlinear dynamics and vibration and application of these concepts to nonlinear engineering problems. Specific topics include: modeling of lumped and continuous nonlinear systems (strings, beams and plates); vibrations of buckled structures; perturbation and other approximate analytical methods; the use and limitations of local linearization; properties of nonlinear behavior, such as dimension and Lyapunov exponents; stability of limit cycles; bifurcations; chaos and chaotic vibrations; experimental methods and data analysis for nonlinear systems. Concepts are reinforced with a number of examples from recently published research. Applications include aeroelastic flutter, impact dynamics, machine-tool vibrations, cardiac arrhythmias and control of chaotic behavior. Credit 3 units. EN: TU

E37 MEMS 5302 Theory of Vibrations

Analytical methods in vibrations. Topics include: Duhamel's integral, Laplace and Fourier transforms and Fourier series with applications to transient response, forced response and vibration isolation; Lagrange's equations for linear systems, discrete systems, degrees of freedom, reducible coordinates, holonomic constraints and virtual work; matrix methods and state variable approach with applications to frequencies and modes, stability and dynamic response in terms of real and complex modal expansions, dynamic response of continuous systems by theory of partial differential equations, Rayleigh-Ritz and Galerkin energy methods, finite difference and finite element algorithms. Credit 3 units. EN: TU

E37 MEMS 5401 General Thermodynamics

General foundations of thermodynamics valid for small and large systems, and for equilibrium and nonequilibrium states. Topics include: definitions of state, work, energy, entropy, temperature, heat interaction and energy interaction. Applications to simple systems; phase rule; perfect and semi-perfect gas; bulk-flow systems; combustion, energy and entropy balances; availability analysis for thermo-mechanical power generation; and innovative energy-conversion schemes. Prerequisite: graduate standing or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5402 Radiation Heat Transfer

Formulation of the governing equations of radiation heat transfer. Topics include: electromagnetic theory of radiation; properties of ideal and real surfaces; techniques for solutions of heat transfer between gray surfaces; radiation in absorbing, emitting and scattering media. Credit 3 units. EN: TU

E37 MEMS 5403 Conduction and Convection Heat Transfer

This course examines heat conduction and convection through various fundamental problems that are constructed from the traditional conservation laws for mass, momentum and energy. Problems include the variable-area fin, the unsteady Dirichlet, Robbins and Rayleigh problems, multidimensional steady conduction, the Couette flow problem, duct convection and boundary layer convection. Though some numerics are discussed, emphasis is on mathematical technique and includes the extended power series method, similarity reduction, separation of variables, integral transforms, and approximate integral methods.

Credit 3 units. EN: TU

E37 MEMS 5404 Combustion Phenomena

Introduction to fundamental aspects of combustion phenomena including relevant thermochemistry, fluid mechanics, and transport processes. Emphasis is on elucidation of the physico-chemical processes, problem formulation, and analytical techniques. Topics covered include ignition, extinction, diffusion flames, particle combustion, deflagrations and detonations. Prerequisites: graduate standing or permission of instructor. (Prior to FL2015, this course was numbered: E33 5404.)

Same as E44 EECE 512

Credit 3 units. EN: TU

E37 MEMS 5410 Fluid Dynamics I

Formulation of the basic concepts and equations governing a Newtonian, viscous, conducting, compressible fluid. Topics include: transport coefficients and the elements of kinetic theory of gases, vorticity, incompressible potential flow; singular solutions; flow over bodies and lifting surfaces; similarity method; viscous flow, boundary layer, low Reynolds number flows, laminar and turbulent flows.

Credit 3 units. EN: TU

E37 MEMS 5411 Fluid Dynamics II

Governing equations and thermodynamics relations for compressible flow. Topics include: kinetic theory of gases; steady, one-dimensional flows with friction and heat transfer; shock waves; Rankine-Hugoniot relations; oblique shocks; reflections from walls and flow interfaces, expansion waves, Prandtl-Meyer flow, flow in nozzles, diffusers and inlets, two- and three-dimensional flows; perturbation methods; similarity rules; compressible laminar and turbulent boundary layers; acoustic phenomena. Emphasis is relevant to air vehicles.

Credit 3 units. EN: TU

E37 MEMS 5412 Computational Fluid Dynamics

Computational fluid dynamics relevant to engineering analysis and design. Topics include: fundamentals of finite-difference, finite-volume and finite-element methods; numerical algorithms for parabolic, elliptic and hyperbolic equations; convergence, stability and consistency of numerical algorithms; application of numerical algorithms to selected model equations relevant to fluid flow, grid-generation techniques and convergence acceleration schemes. Prerequisite: senior or graduate standing or permission of the instructor.

Credit 3 units. EN: TU

E37 MEMS 5413 Advanced Computational Fluid Dynamics

Scope and impact of computational fluid dynamics. Governing equations of fluid mechanics and heat transfer. Three-dimensional grid-generation methods based on differential systems. Numerical methods for Euler and compressible Navier-Stokes equation. Numerical methods for incompressible Navier-Stokes equations. Computation of transonic inviscid and viscous flow past airfoils and wings. Analogy between the equations of computational fluid dynamics, computational electromagnetics, computational aeroacoustics and other equations of computational physics. Non-aerospace applications — bio-fluid mechanics, fluid mechanics of buildings, wind and water turbines, and other energy and environment applications. Prerequisite: MEMS 5412 or permission of the instructor.

Credit 3 units. EN: TU

E37 MEMS 5414 Aeroelasticity and Flow-Induced Vibrations

This course deals with the interactions between aerodynamics, dynamics and structures in aerospace systems. Topics covered include unsteady aerodynamics, finite-state aerodynamic models, classical fixed-wing flutter, rotary-wing aeroelasticity and experimental methods in aeroelasticity. Emphasis is given to the prediction of flutter and limit cycles in aeroelastic systems.

Credit 3 units.

E37 MEMS 5420 HVAC Analysis and Design I

Fundamentals of heating, ventilating, and air conditioning — moist air properties, the psychrometric chart, classic moist air processes, design procedures for heating and cooling systems. Design of HVAC systems for indoor environmental comfort, health, and energy efficiency. Heat transfer processes in buildings. Development and application of techniques for analysis of heating and cooling loads in buildings, including the use of commercial software. Course special topics can include LEED rating and certification, cleanrooms, aviation, aerospace, and naval applications, ventilation loads, animal control facilities, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.

Credit 3 units. EN: TU

E37 MEMS 5421 HVAC Analysis and Design II

Fundamentals of heating, ventilating, and air conditioning — energy analysis and building simulation, design procedures for building water piping systems, centrifugal pump performance, design of building air duct systems, fan performance, optimum space air diffuser design for comfort, analysis of humidification and dehumidification systems, and advanced analysis of refrigeration systems. HVAC analytical techniques will include the use of commercial software. Course special topics can include LEED rating and certification, management for energy efficiency, energy auditing calculations, aviation, aerospace, and naval applications, ventilation loads, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.

Credit 3 units. EN: TU

E37 MEMS 5422 Solar Energy Thermal Processes

Fundamentals of radiation heat transfers and solar radiation, including basic terminology, atmospheric scattering and absorption, radiation interactions with surfaces, and selective surfaces. Components, cycles, and materials of concentrating solar power plants, including parabolic trough and solar towers. Overview over thermal storage, other solar thermal

technologies and photovoltaics. This course includes a final project. Prerequisite: MEMS 3420 or equivalent.
Credit 3 units. EN: TU

E37 MEMS 5423 Sustainable Environmental Building Systems

Sustainable design of building lighting and HVAC systems considering performance, life cycle cost and downstream environmental impact. Criteria, codes and standards for comfort, air quality, noise/vibration and illumination. Life cycle and other investment methods to integrate energy consumption/conservation, utility rates, initial cost, system/component longevity, maintenance cost and building productivity. Direct and secondary contributions to acid rain, global warming and ozone depletion.
Credit 3 units. EN: TU

E37 MEMS 5424 Thermo-Fluid Modeling of Renewable Energy Systems

Overview of sustainable energy systems. Fundamentals of energy conversion. Renewable energy sources and energy conversion from wind, biomass, solar-thermal, geothermal and ocean/waves. Applications to energy storage, fuel cells, green air and ground transportation, energy-efficient buildings. Energy-economics modeling, emissions modeling, global warming and climate change.
Credit 3 units. EN: TU

E37 MEMS 5425 Thermal Management of Electronics

As the demand for higher performance electronics continues its exponential growth, transistor density doubles every 18 to 24 months. Electronic devices with high transistor density generate heat and thus require thermal management to improve reliability and prevent premature failure. Demanding performance specifications result in increased package density, higher heat loads and novel thermal management technology. This course gives an overview of thermal management for micro/power electronics systems and helps engineers to develop a fundamental understanding of emerging thermal technologies. This course will include the following topics: background of electronics packaging; thermal design of heat sinks; single phase and multiphase flow in thermal systems; two-phase heat exchange devices for portable and high powered electronic systems; computational fluid dynamics for design of thermal systems. Prerequisites: senior or graduate standing.
Credit 3 units. EN: TU

E37 MEMS 5500 Elasticity

Elastic constitutive relations for isotropic and anisotropic materials. Formulation of boundary-value problems. Application to torsion, flexure, plane stress, plane strain and generalized plane stress problems. Solution of three-dimensional problems in terms of displacement potentials and stress functions. Solution of two-dimensional problems using complex variables and conformal mapping techniques. Variational and minimum theorems.
Credit 3 units. EN: TU

E37 MEMS 5501 Mechanics of Continua

A broad survey of the general principles governing the mechanics of continuous media. Topics include: general vector and tensor analysis, rigid body motions, deformation, stress and strain rate, large deformation theory, conservation laws of

physics, constitutive relations, principles of continuum mechanics and thermodynamics, two-dimensional continua. Prerequisites: ESE 501–502 or instructor's permission.
Credit 3 units. EN: TU

E37 MEMS 5502 Plates and Shells

Introduction to the linear theory of thin elastic plates and shells. The emphasis is on application and the development of physical intuition. The first part of the course focuses on the analysis of plates under various loading and support conditions. The remainder of the course deals mainly with axisymmetric deformation of shells of revolution. Asymptotic methods are used to solve the governing equations. Applications to pressure vessels, tanks and domes. Prerequisites: BME 240 or MEMS 253; ESE 318 and ESE 319 or equivalent.
Credit 3 units. EN: TU

E37 MEMS 5506 Experimental Methods in Solid Mechanics

Current experimental methods to measure mechanical properties of materials are covered. Lectures include theoretical principles, measurement considerations, data acquisition and analysis techniques. Lectures are complemented by laboratory sections using research equipment such as biaxial testing machines, pressure myographs, indentation devices for different scales, and viscometers.
Credit 3 units. EN: TU

E37 MEMS 5507 Fatigue and Fracture Analysis

The course objective is to demonstrate practical methods for computing fatigue life of metallic structural components. The course covers the three major phases of metal fatigue progression: fatigue crack initiation, crack propagation and fracture. Topics include: stress vs. fatigue life analysis, cumulative fatigue damage, linear elastic fracture mechanics, stress intensity factors, damage tolerance analysis, fracture toughness, critical crack size computation and load history development. The course focus is on application of this technology to design against metal fatigue and to prevent structural failure.
Credit 3 units. EN: TU

E37 MEMS 5510 Finite Element Analysis

Theory and application of the finite element method. Topics include: basic concepts, generalized formulations, construction of finite element spaces, extensions, shape functions, parametric mappings, numerical integration, mass matrices, stiffness matrices and load vectors, boundary conditions, modeling techniques, computation of stresses, stress resultants and natural frequencies, and control of the errors of approximation. Prerequisite: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5515 Numerical Simulation in Solid Mechanics I

Solution of 2D and 3D elasticity problems using the finite element method. Topics include: linear elasticity; laminated material; stress concentration; stress intensity factor; solution verification; J integral; energy release rate; residual stress; multi-body contact; nonlinear elasticity; plasticity; and buckling. Prerequisites: MEMS 424 Finite Elements or MEMS 5704 Aircraft Structures and MEMS 5500 Elasticity or MEMS 5501 Mechanics of Continua and graduate standing or permission of instructor.
Credit 3 units.

E37 MEMS 5516 Numerical Simulation in Solid Mechanics II

Solution of 2D and 3D elasticity problems using the finite element method. Topics include: laminates and composite materials; nonlinear elasticity; plasticity; incremental theory of plasticity; residual stress; geometric nonlinearity; membrane and bending load coupling; multi-body contact; stress intensity factor; interference fit; and buckling analysis. Prerequisite: graduate standing or permission of instructor.

Credit 3 units.

E37 MEMS 5520 Advanced Analytical Mechanics

Lagrange's equations and their applications to holonomic and nonholonomic systems. Topics include: reduction of degrees of freedom by first integrals, variational principles, Hamilton-Jacobi theory, general transformation theory of dynamics, applications such as theory of vibrations and stability of motion, and use of mathematical principles to resolve nonlinear problems. Prerequisite: senior or graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5560 Interfaces and Attachments in Natural and Engineered Structures

Attachment of dissimilar materials in engineering and surgical practice is a challenge. Bimaterial attachment sites are common locations for injury and mechanical failure. Nature presents several highly effective solutions to the challenge of bimaterial attachment that differ from those found in engineering practice. This course bridges the physiologic, surgical and engineering approaches to connecting dissimilar materials. Topics in this course are: natural bimaterial attachments; engineering principles underlying attachments; analysis of the biology of attachments in the body; mechanisms by which robust attachments are formed; concepts of attaching dissimilar materials in surgical practice and engineering; and bioengineering approaches to more effectively combine dissimilar materials.

Credit 3 units. EN: TU

E37 MEMS 5561 Mechanics of Cell Motility

A detailed review of biomechanical inputs that drive cell motility in diverse extracellular matrices (ECMs). This class discusses cytoskeletal machineries that generate and support forces, mechanical roles of cell-ECM adhesions, and regulation of ECM deformations. Also covered are key methods for cell level mechanical measurements, mathematical modeling of cell motility, and physiological and pathological implications of mechanics-driven cell motility in disease and development.

Credit 3 units.

E37 MEMS 5562 Cardiovascular Mechanics

This course focuses on solid and fluid mechanics in the cardiac and cardiovascular system. Cardiac and cardiovascular physiology and anatomy. Solid mechanics of the heart, heart valves, arteries, veins and microcirculation. Flow through the heart chambers and blood vessels. Prerequisites: graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5564 Orthopaedic Biomechanics-Cartilage/Tendon

Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent. Note: BME 590Z (463/563) Orthopaedic Biomechanics—Bones and Joints is *not* a prerequisite.

Credit 3 units. EN: TU

E37 MEMS 5565 Mechanobiology of Cells and Matrices

At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions, and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor.

Credit 3 units. EN: TU

E37 MEMS 5566 Engineering Mechanobiology

Engineering Mechanobiology is a new paradigm for understanding and manipulating the biological function of plants, animals, and their cells. Mechanical force has emerged as a critical component of all biological systems, providing mechanisms to sculpt plants and animals during morphogenesis, to enable cell migration, polarization, proliferation, and differentiation in response to physical changes in the environment, and to modulate the function of single molecules. This course provides a foundation for understanding these factors across plant and animal cells. The course begins with an introduction to plant and animal cell biology and principles of signaling, then progresses to an overview of the cell wall and ECM and an introduction to the mechanics and statistical mechanics of solid, viscoelastic, and fibrous continua. The course then focuses on the questions of how do cells feel, how do cells converse with the ECM and wall, and how do cells remember? Prerequisites: undergraduate calculus and physics.

Credit 3 units. EN: TU

E37 MEMS 5601 Mechanical Behavior of Materials

A materials science-based study of mechanical behavior of materials with emphasis on mechanical behavior as affected by processes taking place at the microscopic and/or atomic level. The response of solids to external or internal forces as influenced by interatomic bonding, crystal/molecular structure, crystalline/noncrystalline defects and material microstructure are studied. The similarities and differences in the response of different kinds of materials viz., metals and alloys, ceramics, polymers and composites are discussed. Topics covered include physical basis of elastic, visco elastic and plastic deformation of solids; strengthening of crystalline materials; visco elastic deformation of polymers as influenced by molecular structure and morphology of amorphous, crystalline and fibrous polymers;

deformation and fracture of composite materials; mechanisms of creep, fracture and fatigue; high strain-rate deformation of crystalline materials; and deformation of noncrystalline materials. Credit 3 units. EN: TU

E37 MEMS 5602 Non-metallics

Structure, mechanical and physical properties of ceramics and cermets, with particular emphasis on the use of these materials for space, missile, rocket, high-speed aircraft, nuclear and solid-state applications. Credit 3 units. EN: TU

E37 MEMS 5603 Materials Characterization Techniques I

An introduction to the basic theory and instrumentation used in transmission electron, scanning electron and optical microscopy. Practical laboratory experience in equipment operations, experimental procedures and material characterization. Credit 3 units. EN: TU

E37 MEMS 5604 Materials Characterization Techniques II

Introduction to crystallography and elements of X-ray physics. Diffraction theory and application to materials science including following topics: reciprocal lattice concept, crystal-structure analysis, Laue methods, rotating crystal methods, powder method, and laboratory methods of crystal analysis. Credit 3 units. EN: TU

E37 MEMS 5605 Mechanical Behavior of Composites

Analysis and mechanics of composite materials. Topics include micromechanics, laminated plate theory, hydrothermal behavior, creep, strength, failure modes, fracture toughness, fatigue, structural response, mechanics of processing, nondestructive evaluation, and test methods. Prerequisite: graduate standing or permission of the instructor. Credit 3 units. EN: TU

E37 MEMS 5606 Soft Nanomaterials

Soft nanomaterials, which range from self-assembled monolayers (SAMs) to complex 3D polymer structures, are gaining increased attention owing to their broad-range applications. The course introduces the fundamental aspects of nanotechnology pertained to soft matter. Various aspects related to the design, fabrication, characterization and application of soft nanomaterials are discussed. Topics covered include but are not limited to SAMs, polymer brushes, layer-by-layer assembly, responsive polymers structures (films, capsules), polymer nanocomposites, biomolecules as nanomaterials and soft lithography. Credit 3 units. EN: TU

E37 MEMS 5607 Introduction to Polymer Blends and Composites

The course covers topics in multicomponent polymer systems (polymer blends and polymer composites) such as: phase separation and miscibility of polymer blends, surfaces and interfaces in composites, microstructure and mechanical behavior, rubber toughened plastics, thermoplastic elastomers, block copolymers, fiber reinforced and laminated composites, techniques of polymer processing with an emphasis on composites processing, melt processing methods such as injection molding and extrusion, solution processing of thin films, selection of suitable processing methods and materials selection

criteria for specific applications. Advanced topics include: nanocomposites such as polymer/CNT composites, bioinspired nanocomposites, and current research challenges. Prerequisite: MEMS 3610 or equivalent or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5608 Introduction to Polymer Science and Engineering

Topics covered in this course are: the concept of long-chain or macromolecules, polymer chain structure and configuration, microstructure and mechanical (rheological) behavior, polymer phase transitions (glass transition, melting, crystallization), physical chemistry of polymer solutions (Flory-Huggins theory, solubility parameter, thermodynamics of mixing and phase separation), polymer surfaces and interfaces, overview of polymer processing (extrusion, injection molding, film formation, fiber spinning) and modern applications of synthetic and biopolymers. Credit 3 units. EN: TU

E37 MEMS 5612 Atomistic Modeling of Materials

This course will provide a hands-on experience using atomic scale computational methods to model, understand and predict the properties of real materials. It will cover modeling using classical force-fields, quantum-mechanical electronic structure methods such as density functional theory, molecular dynamics simulations, and Monte Carlo methods. The basic background of these methods along with examples of their use for calculating properties of real materials will be covered in the lectures. Atomistic materials modeling codes will be used to calculate various material properties. Prerequisites: MEMS 3610 or equivalent or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5700 Aerodynamics

Fundamental concepts of aerodynamics, equations of compressible flows, irrotational flows and potential flow theory, singularity solutions, circulation and vorticity, Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and Prandtl-Glauert rule, supersonic thin airfoil theory, introduction to performance, basic concepts of airfoil design. Prerequisite: graduate standing or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5701 Aerospace Propulsion

Propeller, jet, ramjet and rocket propulsion. Topics include: fundamentals of propulsion systems, gas turbine engines, thermodynamics and compressible flow, one-dimensional gas dynamics, analysis of engine performance, air breathing propulsion system, the analysis and design of engine components, and the fundamentals of ramjet and rocket propulsion. Credit 3 units. EN: TU

E37 MEMS 5703 Analysis of Rotary-Wing Systems

This course introduces the basic physical principles that govern the dynamics and aerodynamics of helicopters, fans and wind turbines. Simplified equations are developed to illustrate these principles, and the student is introduced to the fundamental analysis tools required for their solution. Topics include: harmonic balance, Floquet theory and perturbation methods. Credit 3 units. EN: TU

E37 MEMS 5704 Aircraft Structures

Basic elements of the theory of elasticity; application to torsion of prismatic bars with open and closed thin-wall sections; the membrane analogy; the principle of virtual work applied to 2D elasticity problems. Bending, shear and torsion of open and closed thin-wall section beams; principles of stressed skin construction, structural idealization for the stress analysis of wings, ribs and fuselage structures. Margin of safety of fastened connections and fittings. Stability of plates, thin-wall section columns and stiffened panels. Application of the finite element method for the analysis of fastened connections, structural fittings and problems of local stability of aircraft structural components.

Credit 3 units.

E37 MEMS 5705 Wind Energy Systems

A comprehensive introduction to wind energy systems, a practical means of extracting green and sustainable energy. Topics include: a historical perspective of wind turbines; horizontal axis and vertical axis wind turbines; the basic parameters such as power rating and efficiency; the structural components ranging from blade and hub to nacelle and tower; wind turbine aerodynamics, aeroelasticity and control systems; blade fatigue; statistical wind modeling; unsteady airfoil aerodynamics and downstream wake; and environmental considerations such as noise and aesthetics. Prerequisite: senior or graduate standing in engineering or permission of the instructor.

Credit 3 units. EN: TU

E37 MEMS 5706 Aircraft Performance

This course introduces the principles and applications of aerodynamics to determine the performance of typical jet engine and propeller airplanes. The performance calculations include flight conditions of takeoff, climb, level flight, and landing. The topics covered also include range and endurance computation, turning flight, flight envelope, constraint analysis and design process. The knowledge and skill gained in this course can be readily applied in the preliminary design of an airplane. Prerequisite: senior or graduate standing in engineering, or permission of the instructor.

Credit 3 units. EN: TU

E37 MEMS 5801 Micro-Electro-Mechanical Systems I

Introduction to MEMS: Microelectromechanical systems (MEMS) are ubiquitous in chemical, biomedical and industrial (e.g., automotive, aerospace, printing) applications. This course covers important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course includes discussion of fabrication and measurement technologies (e.g., physical/chemical deposition, lithography, wet/dry etching, and packaging), as well as application of MEMS theory to design/fabrication of devices in a cleanroom. Lectures cover specific processes and how those processes enable the structures needed for accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis systems, biomedical implants, etc. The laboratory component allows students to investigate those processes first-hand by fabricating simple MEMS devices.

Credit 3 units. EN: TU

E37 MEMS 5912 Biomechanics Journal Club

This journal club is intended for graduate students and advanced undergraduates with an interest in biomechanics. We review

landmark and recent publications in areas such as brain, cardiovascular and orthopedic biomechanics, discussing both experimental and modeling approaches. This course meets once weekly at a time to be arranged.

Credit 1 unit. EN: TU

E37 MEMS 597 MEMS Research Rotation

Independent research project that will be determined jointly by the doctoral student and the instructor. Assignments may include background reading, presentations, experiments, theoretical, and/or modeling work. The goal of the course is for the doctoral student to learn the background, principles and techniques associated with research topics of interest and to determine a mutual fit for the student's eventual doctoral thesis laboratory.

Credit 3 units.

E37 MEMS 598 Energy Design Project

Credit variable, maximum 6 units.

E37 MEMS 599 Master's Research

Credit variable, maximum 6 units.

E37 MEMS 600 Doctoral Research

Credit variable, maximum 9 units.

E37 MEMS 883 Master's Continuing Student Status

E37 MEMS 885 Masters Nonresident

Doctoral Degrees

Policies & Regulations

A key objective of the doctoral program is to promote cutting-edge multidisciplinary research and education in the areas of mechanical engineering and materials science. Students are selected for admission to the program by a competitive process, and they typically start in the fall semester. On arriving at Washington University in St. Louis, the student will be advised by the temporary adviser on all procedural issues. The student will choose a permanent adviser by the end of the first year of residency in the program.

The following is a brief summary of the requirements for doctoral students:

1. Pass the qualifying exams. Qualifying exams should be taken by the end of the third semester.
2. Prepare and defend a research proposal. The research proposal should be defended by the end of the fifth semester.
3. Write and successfully defend the doctoral dissertation.
4. Complete a minimum of **36** hours of course credit, and a minimum of **24** credits of doctoral research; total of **72** credits to earn the PhD degree.

- 5. Satisfy the applicable teaching requirements of the Graduate School.

Degrees Offered

The Department of Mechanical Engineering & Materials Science (MEMS) offers the following doctoral degrees:

- PhD in Mechanical Engineering
- PhD in Aerospace Engineering
- DSc in Mechanical Engineering, Aerospace Engineering, or Materials Science

The Doctor of Science (DSc) has similar requirements to the PhD but without the teaching requirement. For a list of differences, please refer to the DSc and PhD Comparison (PDF) (<https://mems.wustl.edu/graduate/programs/Documents/DoctoralComparisonSection.pdf>).

- One may also pursue a PhD in Materials Science — through the Institute of Materials Science & Engineering (IMSE) — but work with professors from the Department of Mechanical Engineering & Materials Science. For details on this program, visit the IMSE Graduate Program (<http://imse.wustl.edu/graduate-program>) webpage.

For more information on MEMS PhD degrees, visit the MEMS Graduate Degree Programs (<https://mems.wustl.edu/graduate/programs/Pages/default.aspx>) webpage.

Master of Science in Mechanical Engineering (MSME)

Master of Science in Mechanical Engineering

Thesis Option

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course work, and a minimum of 6 units must be Master's Research (MEMS 599).

The overall grade-point average must be 2.70 or better.

Courses may be chosen from 400- and 500-level offerings. All must be engineering, math or science courses with the following restrictions:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed, and these must be from courses not required for the BSME degree (if counted for the MSAE) or not required for the BSAE degree (if counted for the MSME degree) with the exception of MEMS 4301 Modeling, Simulation and Control, which can count toward the MS.
- Each course must be approved by the candidate's thesis adviser.

- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- A minimum of 15 units of the total 30 units must be in MEMS courses.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Course Option

The quantitative requirement for the degree is 30 credit hours (normally 10 courses) completed with a grade-point average of 2.70 or better.

Course programs may be composed from one area of specialization below (MSME) or in aerospace engineering (MSAE). They must conform to the following distribution:

Applied Mathematics	6 credits
Area of Specialization	15 credits
Electives	9 credits

Elective courses may be chosen in any area of engineering or mathematics at the 400 level or higher. Of the 30 units, a minimum of 24 must be in 500-level courses. No more than 6 units may be in 400-level courses; but core requirements for the ME undergraduate degree are not allowed with the exception of MEMS 4301 which is allowed. A maximum of 3 credits of Independent Study, MEMS 400 or MEMS 500, may be used as an elective. A minimum of 15 units must be in MEMS. Non-engineering courses (such as T-courses or finance and entrepreneurship) cannot be counted. Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Degree candidates will plan their course programs with the help of a departmental adviser. Use the links below to find courses in the areas of specialization.

Engineering Areas of Specialization for the MS in Mechanical Engineering

- Applied Mechanics (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx>)
- Dynamics/Mechanical Design (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx>)
- Solid Mechanics/Materials Science (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx>)

- Fluid/Thermal Sciences (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx>)
- Energy Conversion and Efficiency (<https://mems.wustl.edu/graduate/programs/Pages/specialized-tracks.aspx>)
- Numerical Simulation in Solid Mechanics (<https://mems.wustl.edu/graduate/programs/Pages/specialized-tracks.aspx>)

Master of Science in Aerospace Engineering (MSAE)

Master of Science in Aerospace Engineering

Thesis Option

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course work, and a minimum of 6 units must be Master's Research (MEMS 599).

The overall grade-point average must be 2.70 or better.

Courses may be chosen from 400- and 500-level offerings. All must be engineering, math or science courses with the following restrictions:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed, and these must be from courses not required for the BSME degree (if counted for the MSAE) or not required for the BSAE degree (if counted for the MSME degree) with the exception of MEMS 4301 which is allowed.
- Each course must be approved by the candidate's thesis adviser.
- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- A minimum of 15 units of the total 30 units must be in MEMS courses.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Course Option

The quantitative requirement for the degree is 30 credit hours (normally 10 courses) completed with a grade-point average of 2.70 or better.

Course programs must be focused in the area of aerospace engineering. They must conform to the following distribution:

Applied Mathematics	6 credits
Aerospace	15 credits
Electives	9 credits

Elective courses may be used to accumulate additional credits in other areas of engineering or in mathematics. A maximum of 3 credits of Independent Study (MEMS 500) may be included as an elective course. A maximum of 6 units of 400-level courses (not required for a MEMS undergraduate degree) with the exception of MEMS 4301 may also be included. Non-engineering courses (such as T-courses or finance and entrepreneurship) cannot be counted as engineering electives. A minimum of 15 units must be in MEMS.

Full-time MS students are required to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Degree candidates will plan their course programs with the help of a departmental adviser.

Master of Science (MS) in Materials Science and Engineering

Master of Science in Materials Science and Engineering

Thesis Option

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course credit, and a minimum of 6 units must be Master's Research (MEMS 599). A minimum of 15 units of the total 30 units must be in MEMS courses.

The overall grade-point average must be 2.70 or better.

Every semester, full-time MS students in Materials Science and Engineering (MSE) are required to take either the department's Graduate Seminar (MEMS 501) or the Graduate Seminar offered by the Institute of Materials Science & Engineering (IMSE 501). These are zero-unit, pass-fail courses.

Degree candidates will plan their programs with the help of their thesis adviser. Courses are to be Engineering courses at the 500 level or above, or Chemistry, Earth and Planetary Science, or Physics courses at the 400 level or above. Course credit must include at least 12 units (four courses) from a list of approved materials-focused courses (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Materials-Science-Engineering.aspx>), found on the MEMS website, as well as 3 units (one course) of mathematics at the graduate level. The following restrictions apply:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed.
- Each course must be approved by the candidate's thesis adviser.
- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- For the combined bachelor's/master's degree (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/bachelors-masters.aspx>), up to 6 units can count for both the BS and the MS, as long as the program of studies satisfies the criteria above.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Course Option

The quantitative requirement for the degree is 30 credit hours (normally 10 courses). A minimum of 15 units of the total 30 must be in MEMS courses.

The overall grade-point average must be 2.70 or better.

Every semester, full-time MSE students are required every semester to take either the department's Graduate Seminar (MEMS 501) or the Graduate Seminar offered by the Institute of Materials Science & Engineering (IMSE 501). These are zero-unit, pass-fail course.

Degree candidates will plan their programs with the help of their faculty adviser. Courses are to be Engineering courses at the 500 level or above, or Chemistry, Earth and Planetary Science, or Physics courses at the 400 level or above. Course credit must include at least 18 units (six courses) from a list of approved materials-focused courses (<https://mems.wustl.edu/graduate/programs/Pages/MS-in-Materials-Science-Engineering.aspx>), found on the MEMS website, as well as 3 units (one course) of mathematics at the graduate level. The following restrictions apply:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed.
- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- For the combined bachelor's/master's degree (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/bachelors-masters.aspx>), up to 6 units can count for both the BS and the MS, as long as the program of studies satisfies the criteria above.

The remaining courses (electives) and may be chosen according to the general criteria above, as long as they contribute to a coherent program of study in materials science.

Master of Engineering (MEng) in Mechanical Engineering

Master of Engineering in Mechanical Engineering

The Master of Engineering in Mechanical Engineering (MEng in ME) is a one- to two-year program offered by the Department of Mechanical Engineering & Materials Science of Washington University in St. Louis. The program is especially tailored for: 1) individuals who plan to change careers and enter the ME profession; 2) international students seeking to establish U.S. credentials in the ME profession; and 3) current professionals working in mechanical engineering who wish to advance their skills and education. A distinctive feature of the program is the ability to customize the course content to meet specific individual needs.

Degree requirements are as follows:

Candidates for admission should have an undergraduate degree in engineering, the physical sciences or mathematics with a GPA of 2.75 or better.

It should be emphasized that, in many states, the MEng in ME will not be sufficient to qualify the degree recipient to sit for a Professional Engineering Exam.

- 30 units of credit in engineering or mathematics courses are required, and these must be at the 400 level or higher. Courses from the other engineering departments (CSE, EECE, ESE and BME) are encouraged. Washington University Continuing Education Courses (i.e., the T-courses or the U-courses) are not permitted.
- All courses must be taken for a grade, with an overall GPA of 2.70 or higher.
- At least 9 of the 30 units must be in MEMS courses at the 500 level.
- All 400-level courses must be either: 1) approved for the Master of Science in Mechanical Engineering (ME) or Aerospace Engineering (AE); or 2) approved by the MEMS faculty for application to the MEng degree.
- No more than 6 units of Independent Study are allowed.
- No more than 6 units may be transferred from another university, and these units must be in engineering or math courses at the 400 level or above, with a grade of B or better, and be courses not required for the candidate's BS degree.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Henry Edwin Sever Institute

With flexible schedules, including evening and weekend classes, professionals can keep their careers moving while developing the knowledge and credentials that will set them apart. Our graduate students strive to make a positive impact on the challenges we face in technology, security and information management. The curriculum and course work will enhance students' knowledge and expertise. They will understand the rapidly changing marketplace and be prepared to set the pace.

Degree Programs

- Master of Construction Management (p. 93)
- Master of Cybersecurity Management (p. 94)
- Master of Engineering Management (p. 95)
- Master of Health Care Operational Excellence (p. 96)
- Master of Information Systems Management (p. 96)
- Master of Project Management (p. 97)

Graduate Certificates

- Graduate Certificate in Construction Management (p. 93)
- Graduate Certificate in Cybersecurity Management (p. 94)
- Graduate Certificate in Information Systems Management (p. 96)
- Graduate Certificate in Project Management (p. 97)

Contact: Kim Simpson
Phone: 314-935-2594
Email: kim.simpson@wustl.edu
Website: <https://sever.wustl.edu>

Courses

Courses include:

- T55 ETEM (p. 85): Engineering Management
- T60 GSever (p. 86): General Professional Education
- T64 CNST (p. 86): Construction Management
- T71 HlthCare (p. 88): Health Care Operations
- T81 INFO (p. 88): Information Management

Engineering Management

Visit online course listings to view semester offerings for T55 ETEM (<https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T55>).

T55 ETEM 500 Independent Study

Credit variable, maximum 6 units.

T55 ETEM 502 Strategic Management of Technology

Analytical methods for strategic management are reviewed. Technology strategy is linked to the strategic plan for the organization, and methods to accomplish this linkage are developed. Factors that characterize and encourage innovation are discussed. A process for managing and integrating new technology into the strategic process is developed. Throughout the course, cases are used to analyze and demonstrate the several elements of strategic management of technology. Prerequisite: graduate standing; permission of instructor required, background or course work in presentation skills is recommended.

Credit 3 units.

T55 ETEM 504 Engineering Management

Discover the full picture of how business works within the organization. This course walks the student through the complete business cycle — the roles the various functions play in a business operation and the interactions between them. To bring these learnings to life, this course also uses management simulation games and classroom competitions. Includes strategy, product planning and management, sales and support, research and development, manufacturing and supply chain, as well as accounting and finance. Prerequisite: graduate standing.

Credit 3 units.

T55 ETEM 505 Decision-Making & Optimization

Expand your ability to analyze and optimize complex business situations by leveraging the key data. Decision-making in today's complex world requires advanced analytical methods and tools, including mathematical modeling and quantitative techniques. Powerful tools for forecasting, finance, operations, production and logistics. Emerging technologies such as the Industrial Internet of Things (IIoT) and Block Chain are enabling a whole new set of possibilities! Prerequisite: graduate standing, statistics.

Credit 3 units.

T55 ETEM 506 Technology Strategy & Marketing

Learn the art and science of technology-rich strategy and marketing. Every business rises and falls on the value it brings to the customer and the value it simultaneously brings to the business itself. The engineer that understands and can communicate strategy and marketing is powerful! Business, technology and research budgets are allocated based on this value proposition, whether the commercialization or operationalization of the technology is one year out or 10 years out. Prerequisite: graduate standing.

Credit 3 units.

T55 ETEM 510 Understanding Emerging & Disruptive Technologies

We live in an era of rapid technology innovation and disruption. Blockbuster was the darling of Wall Street in 2004 and filed for bankruptcy in 2010. Blockbuster CEO in 2008: "Neither Redbox nor Netflix are even on the radar screen in terms of competition." Blockbuster is not alone in their blindness. Microsoft laughed off the first i-phone, and laughed off Google. IBM laughed off the first personal computer. These should be a horrible warning to all business leaders. Numerous technologies are threatening disruption today: block chain, Internet of Things (IoT), artificial intelligence, autonomous vehicles, unmanned aerial vehicles (UAVs), 3D Printing, 5G wireless networks, gene

editing. Understanding what they are and how they might disrupt will make or break countless companies in the coming years.
Prerequisite: graduate standing.
Credit 3 units.

T55 ETEM 521 Human Performance in the Organization

Gain insights and practice in the art and science of leadership. This course addresses the leadership and management capabilities required to move into positions of greater responsibility, with a focus on technology-based organizations. Topics include leadership, goals, motivation and performance, management of change, conflict and effectiveness, organizational development and work design. Because when a leader gets better, everyone gets better.
Credit 3 units.

T55 ETEM 523A Project Planning Methodologies

Build your expertise with today's critical project management methodologies in our fast-paced world. Variations of waterfall are widely used in industry, but new uses of agile are being discovered every day, both inside and outside of software-based organizations. This course exposes the student to the fundamental and emerging techniques and tools to manage successful projects of various sizes and complexity - managing cost, schedule, quality, risk, solution and requirements - while adapting to today's fast-paced and uncertain business environment. The primary focus of this course is on agile.
Prerequisite: graduate standing.
Credit 3 units.

T55 ETEM 534A Principles of Operations Management

Examination of quantitative and managerial approaches for the planning, scheduling and control of production and inventories in manufacturing companies. Review various models for demand forecasting, capacity planning, lot-sizing, scheduling, and shop-floor controls in various types of manufacturing environments. Analysis of techniques such as MRP II, JIT and Kanban in production scheduling and control.
Credit 3 units.

T55 ETEM 535 Productivity & Quality Control

This course provides a comprehensive coverage of quality and productivity improvement concepts for operations management. Students face realities that confront managers involved with the concurrent optimization goals of customer satisfaction and profit improvement. Theoretical and business applications are presented to provide a sound understanding of the basic principles of quality and productivity management in both a manufacturing and services business environment. The student will study contemporary management principles such as: total quality planning using the Malcolm Baldrige assessment, product reliability concepts, statistical process control, outsourcing management, customer requirements evaluation, total cost of quality assessment, productivity performance measurement and control, and others.
Credit 3 units.

T55 ETEM 537 Lean Manufacturing and Management

Lean principles and techniques will be explored and exercised to use as a competitive advantage for manufacturing and engineering-based companies. The driving force and economics of lean, supply chain management, value stream mapping, set-

up reduction, Just-in-Time, managing variations, and cultural issues surrounding lean implementation are examined.
Credit 3 units.

General Professional Education

Visit online course listings to view semester offerings for T60 GSever (<https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T60>).

T60 GSever 502 Financial Principles of the Company

Demystify the fiscal management practices and financial statements of the company. There is a story behind every set of financial data. This course examines the underpinnings of financial accounting and management, including financial reporting processes and uses of accounting data, links between accounting information and management planning, decisions and controls. The course is divided into three phases: (1) introducing financial concepts and principles, (2) performing and evaluating financial analysis, and (3) utilizing case studies to develop a business correction plan for an ailing organization.
Prerequisite: graduate standing.
Credit 3 units.

Construction Management

Visit online course listings to view semester offerings for T64 CNST (<https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T64>).

T64 CNST 523A Construction Cost Estimating

Construction cost estimating explores the application of cost estimating principles and estimating within a project management framework in conjunction with scope definition, quality control, planning and scheduling, risk management and loss prevention techniques, local conditions, information and communication, and working relations with stakeholders. Using a single building project, the course introduces the application of basic quantity surveying and estimating principles using a methodical approach with suggested check lists and techniques for arriving at a reliable cost estimate including direct, indirect, and contingency costs and profits. Student's estimating efforts culminate with a competitive bid day scenario. Prerequisites: T64-573 or permission of instructor.
Credit 3 units.

T64 CNST 550A Special Topics: Sustainable Construction

The course will focus on global, national and regional sustainability issues; history of the movement; ethical issues; ecological design; legal/risk/challenges; costs of green building; national and international green building rating systems; current and potential future trends and successful practices of sustainable planning, design and construction. Also covered is how LEED Accredited Professionals manage the building certification process and documentation required for successful LEED certification. At the end of this course, students should be prepared to take the USGBC LEED Green Associate (GA) Exam Structure and have a working knowledge of the requirements for USGBC LEED v4 Specialty Exams. Additional self-study will be required after the course to fully prepare for any exam.

Prerequisites: graduate standing, and CNST 573 or permission of instructor.
Credit 1.5 units.

T64 CNST 550B Special Topics in Construction Management

This course focuses on the foundational issues of securing new business while ensuring project and company profitability. Topics include creating and implementing marketing and business development strategies; customer relations management; developing competitive strategies for delivering professional construction services; bidding strategies; developing public relations strategies; managerial leadership; strategic planning. Prerequisites: CNST 573 or permission of instructor. In preparation for this course, some study materials will be provided to enrolled students approximately two weeks prior to the first meeting. Section 01: This course is being taught on two consecutive weekends.
Credit 1.5 units.

T64 CNST 550C Special Topics in Construction Management

Fundamentals of the safety management process and the use of safety programs to include hazard recognition, field safety meetings/management, OSHA documentation requirements, coordination of contractor and subcontractor relationship. Prerequisites: graduate standing, and CNST 573 or permission of instructor.
Credit 1.5 units.

T64 CNST 550D Special Topic: Heavy Civil Construction Management

This course provides a broad perspective of the means, methods and procedures associated with managing civil engineering and heavy construction projects. Topics include strategic bidding and estimating, heavy equipment, marine construction heavy civil operations and bridge building. Integration of scheduling, estimating, and construction contracts with a project-based approach. (Three half-day Saturday site visits are required.) Prerequisites: graduate standing, and CNST 573 or permission of instructor.
Credit 3 units.

T64 CNST 572 Legal Aspects of Construction

A survey of the legal problems of the construction manager, including but not limited to, liability in the areas of contracts, agency, torts, insurance, bad judgment and oversight. Prerequisite: graduate standing.
Credit 3 units.

T64 CNST 573 Fundamentals in Construction Management

In this course, students will be exposed to the overall construction process from initial concept through startup of the completed facility. The focus is to provide familiarization of the construction and contracting process and potential involvements by construction managers in the planning, design, construction and post-construction phases. Additional topics are introduced to provide a foundation which will prepare students for future construction management course work. Case studies and industry examples are used throughout the course to authenticate the lectures and assignments. Prerequisite: graduate standing.
Credit 3 units.

T64 CNST 574C Construction Project Planning and Scheduling

Project planning and scheduling process utilizing current techniques including critical path analysis for effective and logical scheduling of construction projects. Identification of project activities and their relationships; schedule development, analysis and updating; relationship of project costs and resources to the schedule; legal implications; effective communication of schedule information; development of procedures to monitor actual field progress; computer application in project scheduling. Prerequisites: T64-573 or permission of instructor.
Credit 3 units.

T64 CNST 579 Advanced Construction Management

A comprehensive study of the operations encountered in the management of a construction firm. Topics include: estimating, scheduling, forms of contracts, risk analysis and management, extra work orders, claims and disputes, construction safety, and contract close-out. Prerequisites: T64-573, T64-574, T64-523A, and permission of program director.
Credit 3 units.

T64 CNST 580B Digital Construction Technology

This course focuses on BIM's philosophy of integration between designers, construction professionals and owners, in order to overcome both technological and implementation changes using Virtual Design and Construction (VDC) and Integrated Project Delivery (IPD). VDC is a methodology that relies on a multidisciplinary collaboration of the digital simulation of design & construction. IPD, on the other hand, integrates people, systems, business structures and practices into a process to optimize efficiency and productivity. In this course, students will learn about BIM's application by exploring 3D, 4D aspects of BIM including geometry, spatial relationships, quantity take off, estimation and scheduling. Along with that, students also will learn about Virtual Design and Construction (VDC) and Integrated Project Delivery (IPD) systems that are integral components of successful BIM projects.
Credit 3 units.

T64 CNST 581A MCM - MArch Capstone Project Phase 1

This capstone course allows MCM/MArch joint degree program students to apply constructability principles to their MArch degree project (A46 ARCH 616) and successfully demonstrate how they have applied those principles. Constructability principles include: analysis of the construction methods and procedures, project cost, time, value, quality and safety. Phase 1 is to be taken simultaneously with A46 ARCH 616 Degree Project. Phase 1 students will develop a constructability review, analysis and plan for their individual project. Prerequisites: admission to MCM/MArch joint program, CNST 573, 523A, 574C.
Credit 1 unit.

T64 CNST 581B MCM - MArch Capstone Project Phase 2

This capstone course allows MCM/MArch joint degree program students to apply constructability principles to their MArch degree project (A46 ARCH 616) and successfully demonstrate how they have applied those principles. Constructability principles include: analysis of the construction methods and procedures, project cost, time, value, quality and safety. Phase 2 is to be taken after completing A46 ARCH 616 Degree Project. Phase 2 students will execute the constructability plan

developed in Phase 1 and prepare and present the deliverables.
Prerequisite: CNST 581A.
Credit 2 units.

Health Care Operations

Visit online course listings to view semester offerings for T71 HlthCare (<https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T71&crslvl=5:8>)

T71 HlthCare 501 Introductory Overview of Operational Excellence in Health Care

This introductory course is designed to prepare students for the Master's of Healthcare Operational Excellence program. Students will learn the fundamentals of operational excellence principles and how the organizational complexities, regulatory and economic framework, and nuances of healthcare impact the ability to apply them. Students will research and explore both healthcare and non-healthcare examples of performance improvement and operational excellence efforts within different organizations and from different stakeholder perspectives. Throughout the course, students will gain an understanding of how the various methods, both social and technical, can play an integral role in achieving operational excellence, and how to identify and mitigate challenges and barriers. Specific methods will include facilitating teams, change management, lean, six sigma, project management and the importance of principle-based deployments rooted in changing behaviors and transforming culture. By completing this introductory overview course, students will understand the level of personal transformation in mindset and skills that will be necessary in order to successfully impact the changes needed for health care operational excellence.

Credit 3 units.

T71 HlthCare 503 Lean Healthcare Concepts, Tools and Lean Management Systems

Students will learn and apply core Lean tools including Value Stream Mapping, 5S, Visual Management, Standard Work, JIT, Push/Pull, Error Proofing, and Daily Management. Critical to applying Lean effectively, participants will also learn how to plan and lead Rapid Improvement Events and other group activities and tactics. This program has been adopted by BJC executive leadership and is identified as a core competency for transformational efforts. Students will also learn the essential elements of a Lean Management System and how to accomplish sustainable results and the development of a continuous improvement culture.

Credit 3 units.

Information Management

Visit online course listings to view semester offerings for T81 INFO (<https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T81&crslvl=5:8>).

T81 INFO 500 Independent Study

Prerequisite: departmental approval.
Credit 3 units.

T81 INFO 503D Applying Innovations within Organizations

This course focuses on how innovations, such as new technologies, find their way into organizations through managerial approaches. Topics will include assimilation and diffusion of technology, effects of technology on organizations and organizations on technology, and how organizations may be analyzed to assess the role of innovations. Emphasis will be placed on how to understand the organization's social system and what can be done to prepare it for an innovation. Disruptive technologies, organizational culture, and how organizations change will also be covered. Prerequisite: appropriate background.

Credit 3 units.

T81 INFO 507D Information Management and Enterprise Transformation

The modern enterprise relies heavily on information management. As enterprises transform to keep pace with business realities such as globalization, mergers/acquisitions, and proliferation of new business models, management needs to reconsider technology infrastructures, social infrastructures, re-engineering business processes, outsourcing, and measuring/managing technology knowledge. The roles of CIOs and IT professionals, power teams, and leadership issues concerning change will be covered.

Credit 3 units.

T81 INFO 509B Leading Teams and Projects

Establishing a personal leadership style, assessing people, and recognizing/establishing authority on a project will be covered. Handling project meetings and dealing with key stakeholder communication will be given emphasis. Teamwork will be highlighted through discussion of various kinds of teams, team structure and team formation. The virtual team style will also be reviewed.

Credit 3 units.

T81 INFO 516B Principles and Practice of Information-Systems Engineering Analysis

This course describes the corporate IS requirements assessment and planning process. It covers the development of an information architecture and a technology architecture. An enterprise model is discussed from the aspects of subject areas, entities and processes. Details concerning data analysis are covered and include data entities, entity attributes, entity relationships, and macro/micro data modeling. Diagramming tools for data modeling will be used. Details of process analysis are covered, and tools will be used for hierarchical decomposition, data flows and action diagrams.

Credit 3 units.

T81 INFO 517 Service Management

This course focuses on the IT service life cycle and its value to the business. This in-depth study of service strategy, service design, service transition, and service operations will provide the student with an understanding of the 26 IT Infrastructure Library (ITIL) processes. Through the application of continuous service improvement, students will understand the IT service life cycle and will also be able to assess the effectiveness of processes and services. This course includes case studies, lectures and group activities to enhance the textbook material.

Credit 3 units.

T81 INFO 527 Introduction to Big Data, Business Process Modeling and Data Management

This course is designed to introduce basic concepts of "Big Data" and the impact these technologies have on society and the enterprise. The course will describe various types of practical "Big Data" implementations, but will focus on the business value that such technologies may allow the enterprise, as well as the risks that can arise from managing the large volume of data that new technology allows. The course will cover a broad spectrum of data fundamental terms, definitions, historical perspectives, and current trends with a focus on big data as a business consideration in an ever-changing world of technological advances and business needs. The course will introduce key big data concepts and terminology that will allow both the business leader and the technical engineer the ability to converse in terms relevant to both disciplines. This course is expected to raise the general awareness of business and technical professionals about the threats, risks and control needs in the cyber-evolving world around them and provide a road map for big data implementations and projects in small and large enterprises.
Credit 3 units.

T81 INFO 535A Economics of Technology

This course is designed to familiarize the student with microeconomic principles and managerial economics. Where possible, the course utilizes examples from technology environments and information systems. The focus is on incentives and decision-making by individuals and firms and the aggregation of these decision-making agents into industries and markets. Business decision-making in the face of changing technology will be emphasized. The principles presented will be relevant both for managing a business as well as evaluating sound public policy.
Credit 3 units.

T81 INFO 5502 The Art and Science of Risk Management

This course focuses on why many project managers miss requirements for schedule, budget or even both. The course concentrates on key risk management techniques practiced by leading project and program managers and taught through fact-filled lecture, case work and project execution as applied to information systems, engineering, financial, product/process and design projects/programs in today's fast-moving environment. Students will take away key value propositions including risk identification, risk quantification, risk monitoring, risk control and risk mitigation. This course will enable the student to address common scope, schedule, quality and cost risk events that occur on complex projects. Project risk management examines the types of risk, with a focus on understanding the process of risk identification, assessment, prevention, mitigation and recovery; governance, auditing, and control of the confidentiality; integrity; and availability of data. Using common operational, strategic, tactical, and technological scenarios, the course work provides a comprehensive approach to the challenges faced by managers where global data is readily available, risk is pervasive, regulations are ever-increasing, and the threat of disruption from potential crises is real.
Credit 3 units.

T81 INFO 5503 Developing Leadership for Professionals

Provides knowledge about a variety of leadership approaches and how they may be effective in technological situations. The

course concentrates on developing skills to actually lead in various situations. These include decision-making, problem solving, coaching, evaluating performance, selling ideas, and gaining commitment. Combines classroom, actual experiences, and reality-based feedback to hone skills resulting in a higher ability to lead.
Credit 3 units.

T81 INFO 5504 Foundations in Project Management

A practical orientation for using what is known about organizations and how to apply this knowledge to managing projects. Review of the project management paradigm, the basic ingredients of a project, critical stakeholders and roles, and the normal project life cycle will be provided. An introduction to the project management mastery model is covered along with explanations for ways to integrate current and future knowledge into the model. How project approaches should differ by how to segment the problem space — monolithic, incremental or evolutionary.
Credit 3 units.

T81 INFO 5506 Group Dynamics in Project Team Performance

This course examines how teams actually work, looking at group behavior in social situations and how various leaders perform in these social situations. Group motivations of teams are also examined in light of the local situation and/or a large enterprise. Identifying the enabling conditions for team formation and the importance of context to team performance. The idea of a standard normal person and how it relates to team behavior. Subject areas covered include: groupthink and the impact on projects; social facilitation with key stakeholders; project uncertainty and the dynamics of contribution; project and organizational climate. Prerequisite: T81-509B.
Credit 3 units.

T81 INFO 5507 Strategies of Projects, Programs and Portfolios

This course addresses the strategic alignment and prioritization of multiple and complex projects with an organization's business objectives and directions. Major areas covered include: stakeholder value, return on investment, balancing the trade-off between project priorities and operational imperative business benefit; establish and implement program governance of multiple projects to ensure consistent alignment with organizational strategy; balancing and coordination of project resources across multiple projects; coordination of schedules among multiple projects using traditional and advanced methods; current trends and practices in program and project portfolio management. Prerequisite: T81-5504.
Credit 3 units.

T81 INFO 5508 Advances in Project Management

This course examines various aspects of organizations and project performance from actual cases. Aspects include the project decision making environment, the enterprise culture, leadership attributes, changes due to project creativity, logic of reasoning within a project and how projects are actually learning environments.
Credit 3 units.

T81 INFO 556 Advanced Risk Analysis and Response Planning

This course develops mastery-level skills to allow the risk practitioner to focus on meeting threat and opportunity uncertainty challenges in rapidly changing project and business environments and on developing competencies needed for the future project and portfolio success. Advance application of quantitative risk analysis, dual contingency analysis, advanced decision analysis, risk valuation, and risk data accuracy/precision are covered. Advanced contingency planning with predictive analytics will be included. Key business environments that would leverage these competencies include information technology, cybersecurity, engineering, manufacturing, procurement and financial services. Focus areas of discussion include: 1. Expose risk practitioners to advanced risk response planning for threat avoidance, mitigation and transferring risk to appropriate stakeholders. Advanced response planning for exploiting, enhancing and sharing opportunities will be addressed. 2. Critical decision analysis incorporating risk will be covered. Key risk management capabilities and trends that affect organizations in the 21st century — cybersecurity, financial uncertainty, global management, entrepreneurship, employee competency risk, team-based management and managing risk threats and opportunities in a competitive and ethical manner — will be examined. 3. Develop competency at predicting the likelihood (probability) and consequence (impact) associated with risk events. This includes determining how project outcome can be affected by known and unknown risks. Prioritization and valuation of multiple risks; determining project risk scores to aid in portfolio analysis, strategic capital allocation and maximizing alignment to business strategies. 4. Expanded quantitative analysis including asymmetrical, symmetrical and uniform probabilistic distribution scenarios. This will include expanded Monte Carlo simulations to predict risk probability of project completing according to baseline schedule, cost, and likelihood of risk occurrence. Expanded decision tree analysis, annotations and calculations will be mastered. 5. Learn how to develop detailed and proactive risk triggers indicative of pending risk event occurrence. Development of secondary risk, contingency plans and fallback plans will also be included. 6. Practical methodology of decision analysis and alternative evaluations of multiple options to select course of action with most probable success and crisis avoidance. Use of Monte Carlo analysis and decision tree analysis will be covered to address risky decisions facing key leaders. Innovation-based risk analysis will be discussed for leading edge technology, cyber and software applications. 7. Current risk certification requirements, corporate application and value proposition for CISSP, PMI-RMP®, etc., will be examined. 8. Threats and opportunities related to corporate procurement applications will be presented for application in outsourcing, contracts, joint ventures/acquisition activities, etc.
Credit 3 units.

T81 INFO 557 Privacy in the Digital Age

The reduction of the cost of storing and manipulating information has led organizations to capture increasing amounts of information about individual behavior. New trade-offs have emerged for parties involved with privacy-enhancing or intrusive technologies: individuals want to avoid the misuse of the information they pass along to others, but they also want to share enough information to achieve satisfactory interactions; organizations want to know more about the parties with which they interact, but they do not want to alienate them with policies deemed as intrusive. Is there a "sweet" spot that satisfies the interests of all parties? Is there a combination of technological

solutions, economic incentives, and legal safeguards that is acceptable for the individual and beneficial to society? Privacy is a complex and multifaceted concept. This course combines technical, economic, legal, and policy perspectives to present a holistic view of its role and value in the digital age. It begins by comparing early definitions of privacy to the current information-focused debate. It then focuses on: technological aspects of privacy (privacy concerns raised by new IT such as the internet, wireless communications and computer matching; tracking techniques and data mining; privacy enhancing technologies and anonymous protocols); economic aspects (economic models of the market for privacy; financial risks caused by privacy violations; the value of customer information); legal aspects (laissez-faire versus regulated approaches; US versus EU legal safeguards); managerial implications (the emerging role of chief privacy officers; compulsory directives and self-regulative efforts); policy aspects (trade-offs between individual privacy rights and societal needs). The course will consist of a combination of readings, assignments and class discussions. Assignments will include essays and technical projects.
Credit 3 units.

T81 INFO 558 Applications of Deep Neural Networks

Deep learning is a group of exciting new technologies for neural networks. Through a combination of advanced training techniques and neural network architectural components, it is now possible to create neural networks of much greater complexity. Deep learning allows a neural network to learn hierarchies of information in a way that is like the function of the human brain. This course will introduce the student to computer vision with Convolution Neural Networks (CNN), time series analysis with Long Short-Term Memory (LSTM), classic neural network structures and application to computer security. High Performance Computing (HPC) aspects will demonstrate how deep learning can be leveraged both on graphical processing units (GPUs), as well as grids. Focus is primarily upon the application of deep learning to problems, with some introduction mathematical foundations. Students will use the Python programming language to implement deep learning using Google TensorFlow and Keras. It is not necessary to know Python prior to this course; however, familiarity of at least one programming language is assumed. This course will be delivered in a hybrid format that includes both classroom and online instruction.
Credit 3 units.

T81 INFO 560 Systematic View of Cybersecurity & Information Assurance

Information security is paramount to the health of a successful enterprise. Learn what it takes to manage and operate an information security program in an enterprise. The focus is on areas such as risk assessment, risk management, incident handling and business continuity planning. Learn the vocabulary, vernacular and terminology used in the information security space. Learn what keeps chief security officers, their teams and the business clients they serve "awake at night," and what you can do, as an information security professional to protect your clients.
Credit 3 units.

T81 INFO 561 A View from the Bridge: Being at the Forefront of Enterprise Information Security

This class discusses the "How-To's" in developing, organizing, staffing and leading an information security organization

from inception through maturity. How it is supported by the CSIS Top 20 Critical Controls will also be a focal point of the course. We will discuss how to manage the harmony between regulatory standards, information security best practices, and organizational practices and procedures in establishing and leading an effective cybersecurity organization. "Because organizations and their information systems constantly change, the activities within the security management process must be revised continuously, in order to stay up-to-date and effective. Security management is a continuous process, and it can be compared to W. Edwards Deming's Quality Circle (Plan, Do, Check, Act)." (Control Case International 2012). Students will study initial security policies that stipulate requirements about ethics, confidentiality and integrity. Techniques for implementing and technical controls for enforcing these policies are investigated, including access control mechanisms, user authentication, configuration and vulnerability management techniques, and networking tools such as firewalls and intrusion detection systems. This course explores, more deeply, the principles of information technology governance, focusing on IT control objectives (COBIT) and related internal controls. Course work provides a deeper understanding of best practices for managing cybersecurity processes and meeting multiple needs of enterprise management by balancing the void between business risks, technical issues, control needs and reporting metrics.

Credit 3 units.

T81 INFO 562 Threat Intelligence & Intrusion Incident Management

This course focuses on gaining the knowledge and insight to defend an enterprise from cyber threats. Using the cyber kill chain process as the organizing construct for the class, students will learn how CISOs defend a company's internal and external environment by protecting, detecting and responding to cyber threats. Students will learn to define critical security teams and controls, effectively organize an incident response team, use cyber threat intelligence, understand network security tools, participate in red and blue team exercises, deploy enterprise digital computer forensics, and conduct targeted cyber threat hunting. Using recent examples of cyber breaches and incidents, students explore how CISOs react and respond to cyber breaches and incidents and learn best practices in doing so. Learning what it takes to build an enterprise-wide cybersecurity awareness program and analysis of cybersecurity vendor resources will also be covered.

Credit 3 units.

T81 INFO 567 Enterprise Network Security

Some of today's most damaging attacks on computer systems involve the exploitation of network infrastructure, either as the target of attack or as a vehicle to advance attacks on end systems. This course provides an in-depth study of the ITIL methodology in securing the network against various attack techniques. It will explore ITIL methods to defend against them. Topics include firewalls and virtual private networks; network intrusion detection; denial of service (DoS) and distributed denial-of-service (DDoS) attacks; DoS and DDoS detection and reaction; worm and virus propagation; tracing the source of attacks; traffic analysis; techniques for hiding the source or destination of network traffic; secure routing protocols; protocol scrubbing; and advanced techniques for reacting to network attacks.

Credit 3 units.

T81 INFO 575 Data Warehousing

This course will introduce students to the major activities involved in data warehousing and its application to a business. The class will concentrate on topics such as: requirements gathering for data warehousing, business constraints, data warehouse technologies and architectures, dimensional model design, entity relationship model design, physical database design for data warehousing, extracting, transforming, and loading strategies, introduction to business intelligence and reporting, expansion and support of a data warehouse. Once the basic principles have been established, the remainder of the class will be built around a group data warehouse project. The project will begin with student groups gathering requirements and developing a data warehouse design. Once the design is complete, students will build a prototype data warehouse containing the necessary structures within their database and populating them with source data. This will require students to develop the table definitions, extract/transformation/load (ETL) logic, and example report definitions. We intend this class to be a hands-on example of a simple data warehouse implementation. Focus areas and skills obtained after completion of the course: gather requirements for data warehousing, explain data warehouse technologies and architecture, understand the advantages and disadvantages of both dimensional and ER modeling for data warehousing, identify data sources, design a physical model for data warehousing, comprehend extract, transform and load strategies, design and develop business reports and business considerations for expanding and supporting a data warehouse.

Credit 3 units.

T81 INFO 576 Predictive Modeling for Large Scale Data Analytics

This course in predictive modeling provides a foundation for large-scale data analytics by teaching statistical analysis and data capture methods for general purpose use across a corporation. Focus areas include large-scale data validation and analysis for competitive business intelligence and security (i.e., cyber intelligence).

Credit 3 units.

T81 INFO 578 Security Auditing

This course provides information technology (IT) professionals an understanding of how security auditing can be successfully integrated as an important component in an effective organizational cybersecurity program. The course provides students practical information to successfully prepare for an internal or external IT audit, use security auditing to reduce risk, and enhance the overall cyber defense environment within their organization. The course provides an overview of the most prevalent types of IT audits affecting organizations, presents a structured methodology for conducting internal audits or preparing for an external audit, and examines challenges and future trends to security auditing brought about by cloud computing, regulatory trends, and other factors. Through the course material, discussions and case studies, students will acquire practical security auditing concepts and principles that can be applied within their organizations to enhance cybersecurity.

Credit 3 units.

T81 INFO 581B Perspectives on Technology and Innovation

Understanding the role that new technologies can play in achieving the strategic vision and thus shareholder value of

the firm will be the focus of this course. This includes reviewing appropriate ways of judging a technology and whether a re-positioned technology can drive business value. Students will participate in a process of discovery and judgment rationalization that will lead to understanding how to bring together the technical and commercial worlds in a profitable way. A discussion of the key concepts that it would take to distinguish between activities and outcomes. Technological innovations (outcomes) are normally the result of product, process, market development and administrative capabilities. Students will discuss strategy, visioning, formulation and execution. How does innovation and growth enter into it? Innovation and growth innovation in design; interaction with customers; in business processes; in management thinking? How you build an innovation strategy will be the capstone of the course.
Credit 3 units.

T81 INFO 584 Communication Excellence for Influential Leadership

Exceptional communicators become extraordinary leaders. This course will guide students to learn to exceptionally communicate their message by applying refined nuances that inspire and transform those with whom they converse. Through a proven communicative process, students will acquire skills necessary to differentiate them as leaders. Students will learn how to communicate across a variety of settings using strategies that result in clear, vivid, and engaging exchanges. Students will practice: storytelling; creating and using clear visuals; engaging listeners; demonstrating passion when speaking; responding to questions with clarity and brevity, and, using their distinctive voice as a leadership asset. Each student will learn how to assess his or her own communication capabilities, adjust to different listeners, and how to evaluate speaker effectiveness and provide valuable feedback to others. Video recordings will be used to demonstrate incremental communicative changes throughout the course, and to show how these strategies bring about outstanding leadership.
Credit 3 units.

T81 INFO 585 Cybersecurity Capstone

The capstone project is a culmination of a student's prior course work and is taken toward the end of their program. It gives the student the opportunity to utilize the hard-earned knowledge and skills they have developed as an MCSM student in a real-world setting. The project gives them a chance to apply business judgment and cybersecurity models to current and emerging opportunities as they confront, create and present a comprehensive cybersecurity plan to a panel of cybersecurity industry experts. MCSM students can choose to apply their efforts for their capstone experience to the strategic benefit of their current companies, while others may desire to display more of a holistic focus to the capstone, taking advantage of the project to understand different industry issues.
Credit 3 units.

T81 INFO 587 Mobile Security and BYOD

The proportion of mobile devices providing open platform functionality is expected to continue to increase in the future. The openness of these platforms offers significant opportunities to all parts of the mobile ecosystem by delivering the ability for flexible program and service delivery options that may be installed, removed or refreshed multiple times in line with the user's needs and requirements. However, with openness comes responsibility, and unrestricted access to mobile resources

and APIs by applications of unknown or untrusted origin could result in damage to the user, the device, the network or all of these. This course will explore how to build and manage suitable security architectures and network precautions.
Credit 3 units.

T81 INFO 588 Cryptography

As the world becomes increasingly dependent on digital communications, computing and information, the need for robust cybersecurity becomes ever more paramount. Within this context, cryptography becomes an indispensable component of any cybersecurity system. The purpose of this course is to equip cybersecurity professionals with a firm understanding of cryptographic principles and applications and how cryptography can be used to secure, protect and safeguard the organization's communications and information. Students will survey the history of cryptography, the evolution of cryptographic algorithms including important symmetric and asymmetric approaches, hashing, authentication and digital signatures, mutual trust, public key infrastructure, key management, user authentication, and cryptographic attacks. Particular focus will be placed on the integration of cryptography within the organization's IT infrastructure to include IPsec; email, wireless, and data encryption and how to analyze, support and present the business case for cryptography in the IT enterprise. Note: Although cryptography is a mathematically intense discipline, the course will be taught from a managerial perspective. As such, the course is self-contained mathematically, and students are not required to have an extensive math background, although some college-based course work is recommended.
Credit 3 units.

T81 INFO 589 Business Continuity and Disaster Recovery

This comprehensive course provides up-to-date assessments and understanding on issues that will affect you and your company. Issues such as earthquakes, hurricanes, acts of terrorism, communication, cybersecurity and news media events will be discussed by an expert who has led disaster recovery efforts through most of these events. Students will have the opportunity to interact with experts in these areas and gain practical knowledge about how to respond and deal with large-scale events affecting the enterprise. By the end of this course, the student will have a thorough comprehension of the tools, knowledge and understanding necessary to assess, benchmark and develop a wide-ranging disaster recovery and business continuity program.
Credit 3 units.

T81 INFO 612 Taking Down the Cyber Criminal – Post Breach

Students will study the management and the communication of information that could be presented in court or could be used to facilitate other information that would be presented in court. The course will review the federal and certain state laws pertaining to the collection of evidence and evidence-related material and the successful submission of evidence to a court. In addition, strategies will be discussed as related to discovery of evidence and evidence-related material and the use of attorney-client privilege and work product to protect the client's interests with respect to such material. The students will also examine when reports should be drafted and examine the proper drafting and use of such reports as a submission to legal counsel, the court or to business. Further, the students will study effective testimony

in a court of law that would include oral testimony and use of demonstrative evidence and material.
Credit 3 units.

Construction Management

The Master of Construction Management/Master of Architecture (MCM/MArch) dual degree program prepares architectural students for the diverse roles within today's multidisciplinary design/construction process. Sam Fox School of Design & Visual Arts architecture students can earn an MArch and an MCM degree in considerably less time than one would need to pursue each degree separately.

The Master of Construction Management is a 30-unit program designed for working professionals. Students will be prepared for every aspect of leading a construction project or organization. Created for any professional of the built environment, our curriculum incorporates traditional themes — cost, time, risk and quality management, strengthened with multidisciplinary topics — business, finance, ethics and law. Lecture and lab-based education provides students with an environment for practical application utilizing best practices that address current issues and developments in the industry. A 15-unit graduate certificate is also offered and can be transferred into the degree at any time.

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/construction-management>

Faculty

Program Director

Steve Bannes
Director of Graduate Studies, Construction Management
Instructor
MS, Southwest Baptist University

For a list of our program faculty (<https://sever.wustl.edu/faculty>), please visit our website.

Requirements

Master of Construction Management/Master of Architecture (Dual Degree Program)

Total units required: 30 (21 School of Engineering & Applied Science units + 9 units of A46 Architecture courses)

In order to earn the degree a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree.

Code	Title	Units
Required: 18 units		
GSever 502	Financial Principles of the Company	3
CNST 523A	Construction Cost Estimating	3
CNST 572	Legal Aspects of Construction	3
CNST 573	Fundamentals in Construction Management	3
CNST 574C	Construction Project Planning and Scheduling	3
CNST 581A	MCM - MArch Capstone Project Phase 1	1
CNST 581B	MCM - MArch Capstone Project Phase 2	2
Elective: Choose 3 units		
ETEM 521	Human Performance in the Organization	3
ETEM 534A	Principles of Operations Management	3
CNST 550A	Special Topics: Sustainable Construction	1.5
CNST 550B	Special Topics in Construction Management	1.5
CNST 550C	Special Topics in Construction Management	1.5
CNST 550D	Special Topic: Heavy Civil Construction Management	3
CNST 579	Advanced Construction Management	3
CNST 580B	Digital Construction Technology	3
INFO 535A	Economics of Technology	3
INFO 5502	The Art and Science of Risk Management	3
INFO 5503	Developing Leadership for Professionals	3
INFO 5504	Foundations in Project Management	3
INFO 584	Communication Excellence for Influential Leadership	3

Master of Construction Management

Total units required: 30

In order to earn the degree/certificate a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree/certificate.

Code	Title	Units
Required: 18 units		
GSever 502	Financial Principles of the Company (*)	3
CNST 523A	Construction Cost Estimating (*)	3
CNST 572	Legal Aspects of Construction (*)	3
CNST 573	Fundamentals in Construction Management (*)	3
CNST 574C	Construction Project Planning and Scheduling (*)	3
CNST 579	Advanced Construction Management	3
Electives: Choose 12 units		
ETEM 521	Human Performance in the Organization	3
ETEM 534A	Principles of Operations Management	3
CNST 550A	Special Topics: Sustainable Construction	1.5
CNST 550B	Special Topics in Construction Management	1.5
CNST 550C	Special Topics in Construction Management	1.5
CNST 550D	Special Topic: Heavy Civil Construction Management	3
CNST 580B	Digital Construction Technology	3
INFO 535A	Economics of Technology	3
INFO 5502	The Art and Science of Risk Management	3
INFO 5503	Developing Leadership for Professionals	3
INFO 5504	Foundations in Project Management	3
INFO 584	Communication Excellence for Influential Leadership	3

(*) Courses required to earn a 15-unit Graduate Certificate in Construction Management

Cybersecurity Management

Securing an organization's data requires a combination of technical skills, innovative concepts, and managerial acumen. The Master of Cybersecurity Management at Washington University is a 36-unit, part-time program designed for working professionals. This program was developed with one critical goal: educate professionals on how to manage the people and resources who perform these tasks and to lead the cybersecurity function in organizations.

The curriculum provides students with the knowledge needed to protect, defend, respond and recover from cyber threats. Graduates of this program will be equipped to design, engineer and assess global cybersecurity problems while maintaining the vision and strategy of the enterprise.

1. Graduate Certificate (15 units, 10-15 months to complete)
2. Part-time Master's Degree (36 units, 2.5 years+ to complete)

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/cyber-security-management>

Faculty

Program Director

Joe Scherrer
Director of Graduate Studies, Cybersecurity Management and Information Systems Management
MS, Boston University

For a list of our program faculty (<https://sever.wustl.edu/faculty>), please visit our website.

Requirements

Master of Cybersecurity Management

Total units required: 36

In order to earn the degree/certificate a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree/certificate.

Code	Title	Units
Required Courses: Choose 15 units		
INFO 5502	The Art and Science of Risk Management (*)	3
INFO 560	Systematic View of Cybersecurity & Information Assurance (*)	3
INFO 561	A View from the Bridge: Being at the Forefront of Enterprise Information Security (*)	3
INFO 562	Threat Intelligence & Intrusion Incident Management (*)	3
INFO 567	Enterprise Network Security (*)	3
INFO 581B	Perspectives on Technology and Innovation	3
INFO 612	Taking Down the Cyber Criminal – Post Breach	3
Business & Organizational Courses: Choose 9 units		
GSever 502	Financial Principles of the Company	3
INFO 507D	Information Management and Enterprise Transformation	3
INFO 509B	Leading Teams and Projects	3
INFO 5503	Developing Leadership for Professionals	3

INFO 5506	Group Dynamics in Project Team Performance	3
INFO 584	Communication Excellence for Influential Leadership	3
B66 OB 524	Negotiation	3
Elective Courses: Choose 9 units		
INFO 5504	Foundations in Project Management	3
INFO 556	Advanced Risk Analysis and Response Planning	3
INFO 557	Privacy in the Digital Age	3
INFO 575	Data Warehousing	3
INFO 578	Security Auditing	3
INFO 587	Mobile Security and BYOD	3
INFO 588	Cryptography	3
Capstone: Required		
INFO 585	Cybersecurity Capstone	3

(*) Courses required to earn a 15-unit Graduate Certificate in Cybersecurity Management

Engineering Management

The newly revised Master of Engineering Management program bridges the gap between technology and business, by providing students with technical expertise and leadership skills needed to advance their career. The 30-unit Master of Engineering Management is available for full-time or part-time students.

This program brings together Washington University in St. Louis faculty and industry-leading experts to help students learn to strategize, lead, make informed decisions and manage financials. Courses prepare individuals to utilize common management tactics across all of the engineering disciplines. Students can choose from concentrations in cybersecurity, data analytics, or leadership and organizational behavior.

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/engineering-management>

Faculty

Program Director

Peggy Kepuraitis Matson (<https://sever.wustl.edu/faculty/Pages/Peggy-Kepuraitis-Matson.aspx>)
Director of Graduate Studies, Engineering Management and Project Management
MBA, University of Chicago
MSEECs, University of Chicago

For a list of our program faculty (<https://sever.wustl.edu/faculty>), please visit our website.

Requirements

Master of Engineering Management

Total units required: 30

In order to earn the degree a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree.

Code	Title	Units
Required Courses: 21 units		
ESEM 504	Engineering Management	3
GSever 502	Financial Principles of the Company	3
ESEM 505	Decision-Making & Optimization	3
ESEM 506	Technology Strategy & Marketing	3
ESEM 510	Understanding Emerging & Disruptive Technologies	3
ESEM 521	Human Performance in the Organization	3
ESEM 523A	Project Planning Methodologies	3
Cybersecurity Concentration: Choose 9 units		
INFO 560	Systematic View of Cybersecurity & Information Assurance	3
INFO 561	A View from the Bridge: Being at the Forefront of Enterprise Information Security	3
INFO 562	Threat Intelligence & Intrusion Incident Management	3
INFO 567	Enterprise Network Security	3
INFO 612	Taking Down the Cyber Criminal – Post Breach	3
INFO 557	Privacy in the Digital Age	3
INFO 587	Mobile Security and BYOD	3
INFO 588	Cryptography	3
Data Analytics Concentration: Choose 9 units		
INFO 527	Introduction to Big Data, Business Process Modeling and Data Management	3
INFO 558	Applications of Deep Neural Networks	3
INFO 575	Data Warehousing	3
INFO 576	Predictive Modeling for Large Scale Data Analytics	3
CSE 511A	Introduction to Artificial Intelligence	3
Leadership & Organizational Behavior Concentration: Choose 9 units		
INFO 5506	Group Dynamics in Project Team Performance	3
INFO 509B	Leading Teams and Projects	3

INFO 5503	Developing Leadership for Professionals	3
INFO 584	Communication Excellence for Influential Leadership	3
B66 OB 524	Negotiation	3

Health Care Operational Excellence

The quality and efficiency of health care systems are of increasing importance at every level and dimension of society. The 30-unit Master of Health Care Operational Excellence is designed to prepare students to create, lead and manage the continuous improvement of processes in clinical operations.

This program is designed to create thought leaders in continuous improvement, employee engagement, value-stream mapping and operational excellence. Focused on continuous improvement methodologies, the curriculum offered in this degree prepares leaders in service, health care and other operational environments to utilize a toolset allowing them to eliminate waste, innovate and improve patient and employee experiences in St. Louis and around the globe.

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/healthcare-operational-excellence>

Faculty

Program Director

Leroy Love (<https://sever.wustl.edu/faculty/Pages/default.aspx>)
Director of Graduate Studies in Health Care Operational Excellence

For a list of our program faculty (<https://sever.wustl.edu/faculty>), please visit our website.

Requirements

Master of Health Care Operational Excellence

Total units required: 30

In order to earn the degree a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree.

Required courses: 27 units, including:*

Code	Title	Units
HlthCare 501	Introductory Overview of Operational Excellence in Health Care	3

HlthCare 502	Facilitation Skills/Change Management	3
HlthCare 503	Lean Healthcare Concepts, Tools and Lean Management Systems	3
INFO 5504	Foundations in Project Management	3
INFO 5502	The Art and Science of Risk Management	3

Electives: 3 units

* Additional courses will be added to the curriculum. Please visit our curriculum webpage (<https://sever.wustl.edu/degreeprograms/healthcare-operational-excellence/Pages/Healthcare-Operational-Excellence-Curriculum.aspx>) for the most current information regarding this program.

Information Systems Management

Building on more than 30 years of innovative graduate education and professional development programs in information technology, the School of Engineering & Applied Science at Washington University in St. Louis now offers a new 30-unit Master of Information Systems Management. This new program combines the best of two very successful programs that have attracted students from across the world: the Master of Information Systems, and the Master of Information Management.

The new integrated program is a key component in Washington University's strategy to prepare the next generation of technology leaders. Offered through the Sever Institute, the 30-unit Master of Information Systems Management brings together candidates with interests and backgrounds in technology and management into a blend of outstanding courses led by Washington University faculty and industry leaders in information, systems, management and leadership. Students may pursue the program full-time or part-time. A 15-unit Graduate Certificate in Information Systems Management is also offered and can be transferred into the degree program at any time.

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/information-systems-management>

Faculty

Program Director

Joe Scherrer (<https://sever.wustl.edu/faculty/Pages/Joe-Scherrer.aspx>)

Director of Graduate Studies, Cybersecurity Management and Information Systems Management
MS, Boston University

For a list of our program faculty (<https://sever.wustl.edu/faculty/>), please visit our website.

Requirements

Master of Information Systems Management

Total units required: 30

In order to earn the degree/certificate a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree/certificate.

Code	Title	Units
Required Courses: 6 units		
INFO 527	Introduction to Big Data, Business Process Modeling and Data Management (*)	3
INFO 5502	The Art and Science of Risk Management (*)	3
Technical Courses: Choose 6 units		
INFO 507D	Information Management and Enterprise Transformation (*)	3
INFO 558	Applications of Deep Neural Networks	3
INFO 581B	Perspectives on Technology and Innovation (*)	3
CSE 530S	Database Management Systems	3
Management Courses: Choose 6 units		
INFO 517	Service Management	3
INFO 584	Communication Excellence for Influential Leadership	3
ETEM 502	Strategic Management of Technology (*)	3
GSever 502	Financial Principles of the Company	3
INFO 5503	Developing Leadership for Professionals	3
INFO 5506	Group Dynamics in Project Team Performance	3
Elective Courses: Choose 9 units		
INFO 509B	Leading Teams and Projects	3
INFO 5504	Foundations in Project Management	3
INFO 557	Privacy in the Digital Age	3

INFO 560	Systematic View of Cybersecurity & Information Assurance	3
INFO 575	Data Warehousing	3
INFO 576	Predictive Modeling for Large Scale Data Analytics	3
INFO 589	Business Continuity and Disaster Recovery	3
CSE 511A	Introduction to Artificial Intelligence	3
CSE 514A	Data Mining	3
B66 OB 524	Negotiation	3
Capstone: Required		
INFO 585	Cybersecurity Capstone	3

(*) Courses required to earn a 15-unit Graduate Certificate in Information Systems Management

Project Management

Successful project managers are capable of consistently executing complex projects on time and on budget. There are key components that make this possible, such as the ability to motivate and lead a team, formulate effective plans, understand risk, and communicate effectively with stakeholders.

The curriculum in this program was designed to execute mission-critical projects and conquer the three project environments of people, processes and strategies. The 36-unit master's degree can be taken in a part-time or full-time format. A 15-unit Graduate Certificate in Project Management is also offered and can be transferred into the degree at any time.

Contact: Kim Simpson
Phone: 314-935-2594
Website: <https://sever.wustl.edu/degreeprograms/project-management>

Faculty

Program Director

Peggy Kepuraitis Matson (<https://sever.wustl.edu/faculty/Pages/Peggy-Kepuraitis-Matson.aspx>)

Director of Graduate Studies, Engineering Management and Project Management
MBA, University of Chicago
MSEECs, University of Chicago

For a list of our program faculty (<https://sever.wustl.edu/faculty/>), please visit our website.

Requirements

Master of Project Management

Total units required: 36

In order to earn the degree/certificate a student must have a cumulative grade point average of at least 2.70 over all courses applied toward the degree/certificate.

Code	Title	Units
Required Courses: 24 units		
ETEM 523A	Project Planning Methodologies (*)	3
INFO 503D	Applying Innovations within Organizations (*)	3
INFO 509B	Leading Teams and Projects (*)	3
INFO 5503	Developing Leadership for Professionals	3
INFO 5504	Foundations in Project Management (*)	3
INFO 5506	Group Dynamics in Project Team Performance	3
INFO 5507	Strategies of Projects, Programs and Portfolios (*)	3
INFO 5508	Advances in Project Management	3
Elective Courses: Choose 12 units		
ETEM 502	Strategic Management of Technology	3
ETEM 534A	Principles of Operations Management	3
ETEM 535	Productivity & Quality Control	3
INFO 507D	Information Management and Enterprise Transformation	3
INFO 535A	Economics of Technology	3
INFO 5502	The Art and Science of Risk Management	3
GSever 502	Financial Principles of the Company (**)	3
CNST 523A	Construction Cost Estimating (**)	3
CNST 572	Legal Aspects of Construction (**)	3
CNST 573	Fundamentals in Construction Management (**)	3
CNST 574C	Construction Project Planning and Scheduling (**)	3

(*) Courses required to earn a 15-unit Graduate Certificate in Project Management

(**) Courses required to earn a 15-unit Graduate Certificate in Construction Management

Degrees Offered

- Aerospace Engineering (MS, DSc, PhD) (p. 73)
- Biomedical Engineering (MS, PhD) (p. 16)
- Biomedical Innovation (MEng) (p. 16)
- Computer Engineering (MS, PhD) (p. 26)
- Computer Science (MEng, MS, PhD) (p. 26)

- Construction Management (Master, Certificate) (p. 93)
- Control Engineering (Master) (p. 40)
- Cybersecurity Engineering (MS) (p. 38)
- Cybersecurity Management (Master, Certificate) (p. 94)
- Data Mining and Machine Learning (Certificate) (p. 39)
- Electrical Engineering (MS, DSc, PhD) (p. 40)
- Energy, Environmental & Chemical Engineering (MEng, MS, PhD) (p. 54)
- Engineering Data Analytics and Statistics (MS) (p. 40)
- Engineering Management (Master) (p. 95)
- Health Care Operational Excellence (Master) (p. 96)
- Imaging Science & Engineering (Certificate) (p. 40)
- Imaging Science (Interdisciplinary PhD) (p. 61)
- Information Systems Management (Master, Certificate) (p. 96)
- Materials Science & Engineering (MS, DSc (p. 73), PhD (p. 67))
- Mechanical Engineering (MEng, MS, DSc, PhD) (p. 73)
- Medical Physics (Post-PhD Certificate) (p. 16)
- Project Management (Master, Certificate) (p. 97)
- Robotics (MEng) (p. 40)
- Systems Science & Mathematics (MS, DSc, PhD) (p. 40)

Administration

Dean's Office
314-935-6350

Department of Biomedical Engineering
314-935-6164

Department of Computer Science & Engineering
314-935-6160

Department of Electrical & Systems Engineering
314-935-5565

Department of Energy, Environmental & Chemical Engineering
314-935-5548

Department of Mechanical Engineering & Materials Science
314-935-6047

Engineering Information Technology
314-935-5097

Engineering Undergraduate Student Services
314-935-6100

Engineering Graduate Student Services

314-935-5830

Sever Institute

314-935-5484

Admission Procedures

Eligibility

Washington University encourages and gives full consideration to all applicants for admission and financial aid without regard to race, color, age, religion, sex, sexual orientation, gender identity or expression, national origin, veteran status, disability, or genetic information.

The School of Engineering & Applied Science is strongly interested in recruiting, enrolling, retaining, and graduating students from diverse backgrounds. Applications for admission by students from diverse backgrounds to any of our degree programs are encouraged and welcomed. To the greatest extent possible, students with disabilities are integrated into the student population as equal members.

To be considered for admission into a graduate degree program, applicants must hold a bachelor's degree from an accredited institution, prior to starting the graduate program. Most of the Engineering degree programs require a previous degree in science, technology, engineering or mathematics.

Current Engineering graduate students who wish to be admitted into another Engineering graduate program must be admitted at least one semester prior to their anticipated graduation semester.

Students may be admitted to study for the PhD degree directly from baccalaureate study or after undertaking other graduate or professional education, whether at Washington University or at another accredited institution.

Application Process

Degree programs set their own application deadlines, which must be no later than January 15 for doctoral programs. Master's program deadlines are later; applicants should check deadlines (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/application-process.aspx>) through the School of Engineering & Applied Science website. It is generally advantageous to the applicant to complete the application well in advance of the deadline.

The application (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/default.aspx>) is available online through the School of Engineering website. Applications are ready for final consideration after the required items from the application checklist have been submitted.

All applicants for full-time graduate programs are required to submit Graduate Record Examination (GRE) scores at the time of application, with the exception of the Master of Engineering

degree in Biomedical Innovation program in Biomedical Engineering. Official test scores are required at the time of application.

Admissions and financial aid awards are for a specific academic year; students who do not matriculate that year must normally reapply. Admitted students can request a deferral of admission for up to one year, but such special requests require approval both of the admitting program and the admissions office. Applicants to whom admission is not offered may reapply to a future semester.

Admission of International Students

International students considering application to Washington University for graduate study should have a general familiarity with academic practices and university customs in the United States. All international students are required to present evidence of their ability to support themselves financially during graduate study. International students whose native language is not English must submit score reports from the Test of English as a Foreign Language (TOEFL). The test should be taken in time for results to reach Washington University directly from Educational Testing Service (ETS) before the application deadline. Official test scores are required at the time of application.

The TOEFL requirement may be waived during the application process with a minimum of three years of documented study at a U.S. institution or an institution in a country where English is the primary language spoken.

Students Not Candidate for Degree (SNCD)

SNCD admission may be granted to qualified students who hold a bachelor's degree or its equivalent, who wish to enroll in graduate courses on a non-degree basis, and who receive approval from a degree program. Examples include students in good standing at other graduate schools and students who wish to test their capabilities in a graduate setting. Students in this category may take a maximum of 9 units, but may later apply to a degree program and transfer these units to meet degree requirements. SNCD students are not eligible for Title IV Federal Funding.

Academic Policies

The policies below are relevant for DSc and master's students in the School of Engineering & Applied Science (SEAS). To view policies for PhD students, please refer to the Academic Information (<http://bulletin.wustl.edu/grad/gsas/phd/academic>) section of the *Graduate School Bulletin*.

Courses

To count toward a graduate degree, courses must be offered at the graduate level, taken for a grade, and approved in advance by the student's adviser and program as eligible to count toward the student's degree. Depending on the program, graduate-level work begins with courses numbered at the 400 or 500 level. Audited courses and courses taken pass/fail cannot be counted toward the degree. Students should consult their advisers regarding these options.

ELP English Placement Exams (<http://oiss.wustl.edu/english-language-programs/testing/schedule>): These exams are taken by new international graduate students (in any graduate degree program) upon arrival. Students may be placed into a seminar series to ensure success in graduate programs.

Course Load

The normal load for full-time graduate students is 9-12 units per semester. The course selection and load must be worked out with and approved by the student's adviser. Graduate students with research and assistantship duties will typically enroll for course loads commensurate with the requirements of these duties. The course load will be determined after consultation with the student's adviser and the person supervising the student's duties as a research assistant or assistant in instruction. Students otherwise employed full- or part-time, on- or off-campus, will determine a satisfactory reduced course load with their advisers. International students on student visas are required to maintain full-time enrollment status.

Registration

WUSTL Key

Students will use their WUSTL Key login credentials at many important Washington University websites, including WebSTAC (for registration), to access email, Habif Health and Wellness Center, and Student Financial Services.

- WUSTL Key activation information is emailed to newly admitted students by the Office of the University Registrar. WUSTL Key activation emails are delivered to the email address provided on the graduate application.
- If a student does not receive their WUSTL Key activation email, they should contact the Office of the University Registrar by email (registrarwustlkey@email.wustl.edu) or call 314-935-5959.
- If a student has already created their WUSTL Key but has forgotten it, they can retrieve their login ID and/or password by going to the WUSTL Key website (<http://wustlkey.wustl.edu>) or from the WebSTAC login screen and most other login screens where their WUSTL Key is accepted.
- Students should log into WebSTAC (<https://webstac.wustl.edu>) to ensure their access.

All graduate students in Engineering must register each fall and spring semester until all degree requirements are complete.

All registrations require online approval by the student's faculty adviser. Students may register in one of three categories:

- **Active Status:** A graduate student is viewed as having an active full-time status if enrolled in nine (9) or more units or an active part-time status if enrolled in fewer than nine (9) units. Graduate students must be authorized by their adviser prior to registration. International master's students on F1 and J1 visas are required to take a minimum of 9 units per semester except in their final semester. In order to have part-time status in their final semester, international master's students must complete a Reduced Course Load form available from the Office of International Students and Scholars (OISS).
- **Continuing Student Status:** The Continuing Student Status course option may be used when graduate students are approved to register for fewer than 9 units but still need to maintain their full-time status. When students are registered for the Master's Continuing Student Status (883) course or the Doctoral Continuing Student Status (884) course, they will still be viewed as having a full-time status, even if they are taking fewer than 9 units. Both placeholder courses are 0-unit audit courses with no tuition charges associated with them for engineering students; however, students may be charged health insurance and/or student activity fees associated with full-time status. The Txx or Exx 883 and Exx 884 course options are contingent upon adviser and departmental approval. **Note:** The 883 status is not available for master's students on F1 and J1 visas; domestic master's students may register under the 883 status only in their final semester with departmental approval. The 884 course is for DSc students only. Engineering PhD students will register for the LGS 9000 Full-Time Graduate Research/Study placeholder course to maintain full-time status.
- **Nonresident or Inactive Status:** Graduate students who do not need to maintain full-time status and who do not need to register for any course or research units during a given semester should, with departmental and adviser approval, register under the Nonresident/Inactive Status placeholder course option. Graduate students on an official leave of absence should also register under this status but, again, only with adviser and departmental approval. (*Note:* PhD students in this situation must use Leave of Absence forms or other forms provided by the Graduate School). A DSc student wishing to register under a nonresident/inactive status should register using the Exx 886 course number. A master's student should register for the nonresident/inactive status using the Txx or Exx 885 course number. Both placeholder courses are 0-unit audit courses with no tuition charges associated with them for engineering students. Students registered this way are not viewed as full-time and will not automatically have university health insurance fees or coverage. This registration does not defer

student loans, and it does not serve as a legal status for international students. The nonresident/inactive status will assure that the student's major program will remain open. This option is not available to international students (due to F1 and J1 visa requirements), unless approved by the Office for International Students and Scholars. A nonresident/inactive status is allowed only for a few semesters, at the department's discretion. Any student contemplating a nonresident/inactive status must remember to be aware of the residency requirements and the total time limitation required for degree completion.

Graduate Student Reinstatement: Graduate students who do not register in one of the above categories will have to apply for reinstatement if they wish to re-enroll at a future time. For reinstatement information, master's and DSc students should contact Engineering Student Services at 314-935-6100, and PhD students should contact the Graduate School at 314-935-6880. Students seeking reinstatement may be required to pay a reinstatement fee, take special reinstatement examinations, and repeat previous work if it fails to meet contemporary standards. Candidates for the DSc degree who apply for reinstatement may be required to repeat qualifying examinations.

Grades

Graduate work is graded on a scale of A, B, C, D, P, and F (failure), with the auxiliary marks of I (incomplete), X (no final examination), and N (no grade submitted). Audit grades are L (successful audit) and Z (unsuccessful audit). The School of Engineering uses a 4-point scale for calculating grade point averages, with A = 4, B = 3, and C = 2. A plus adds .3 to the value of a grade, whereas a minus subtracts .3 from the value of a grade.

A grade of I or X in a course other than research must be removed no later than the close of the next semester; if not, the I or X turns into an F at the end of the next regular semester after the I or X grade was assigned.

Academic Probation and Suspension

Satisfactory academic progress is a prerequisite for continuation in engineering degree programs. Most financial awards, and all federally funded awards, are contingent upon the maintenance of satisfactory academic progress. The following are minimal standards of satisfactory academic progress for Doctor of Science and Master's students. Degree programs may set stricter standards but may not relax these listed below. Acceptability of grades below B- for fulfillment of degree requirements is determined by individual departments.

Doctor of Science (DSc) students must maintain a cumulative grade point average of at least 3.00.

- Academic probation occurs if a semester or cumulative grade-point average drops below 3.00.

- A DSc student is eligible for academic suspension if any one of the following occurs:
 - Receives an F grade in a course, or
 - Earns a semester or cumulative grade point average less than 2.00, or
 - Has been on probation for two semesters and has not attained a 3.00 cumulative grade point average.

Master's students must maintain a cumulative grade point average of at least 2.70.

- Academic probation occurs if a semester or cumulative grade-point average drops below 2.70.
- A master's student is eligible for academic suspension if any one of the following occurs:
 - Receives an F grade in a course, or
 - Earns a semester or cumulative grade point average less than 2.00, or
 - Has been on probation for two semesters and has not attained a 2.70 cumulative grade point average.

Academic **probation** represents a warning that things are not going well academically. Students placed on academic probation may continue to stay enrolled in their degree programs, but they are strongly encouraged to meet with their advisers to discuss what they might do to improve their grades.

Academic **suspension** represents being dismissed from the school. Students placed on academic suspension are not eligible to enroll or continue their degree programs.

Students suspended may petition the registrar in the School of Engineering & Applied Science for reinstatement. Reinstatement petitions will be referred to the Graduate Board for review. If a student decides not to appeal an academic suspension, or if a student's appeal is not successful, registration for the upcoming semester will be cancelled and the student's academic record will be closed. If this should occur it may be possible for a student to apply for re-enrollment at Washington University in St. Louis at a future time. Students in this situation will need to show that they have successfully completed challenging full-time course work at a different institution (generally, at least for one year), or be employed in a full-time position (generally, at least for one year), or a combination of the two (school and work). There is no guarantee that students who have been suspended will be allowed to return.

A grade of I or X in a course other than research must be removed no later than the close of the next semester; if not, the I or X turns into an F at the end of the next regular semester after the I or X grade was assigned. Students are eligible for suspension after an I or X grade changes to an F grade.

Satisfactory academic progress for engineering students in PhD programs is monitored by the Graduate School as well as the degree program. Please refer to the Academic Information (<http://bulletin.wustl.edu/grad/gsas/phd/academic>) section of

the *Graduate School Bulletin* for specific information related to policies concerning PhD students.

Satisfactory Academic Progress and Title IV Financial

Aid: Federal regulations require that students receiving federal Title IV financial aid maintain satisfactory academic progress (SAP). SAP is evaluated annually at the end of the spring semester. In order to be considered to be maintaining SAP, and thus be eligible for federal financial aid, a student must maintain minimum requirements for cumulative grade point average (≥ 2.70 for master's and ≥ 3.0 for DSc) and pace (credit earned for at least 67 percent of the credits attempted). The degree must also be completed within the maximum time frame allowed for the program (defined as 150 percent of the required credits). Students who are not maintaining progress will be notified by Engineering Student Services and — barring an approved appeal — are ineligible for aid for future semesters. PhD students should refer to the *Graduate School Bulletin* for specific information related to SAP. Additional information about SAP is available from Student Financial Services (<https://sfs.wustl.edu/resources/Pages/Satisfactory-Academic-Progress.aspx>).

Repeating a Course

If an Engineering graduate student repeats a course at Washington University, only the second grade is included in the calculation of the grade point average. Both enrollments and grades are shown on the student's official transcript. The symbol R next to the first enrollment's grade indicates that the course was later retaken. Credit toward the degree is allowed for the latest enrollment only.

Transfer Credit

A maximum of 6 units of graduate credit obtained at institutions other than Washington University may be applied toward the master's degree. Approved transfer credit for undergraduate course work completed at a different institution cannot be posted until a letter is received from that institution's registrar, which states the graduate-level course work was not used to satisfy undergraduate degree requirements.

A maximum of 24 units of graduate credit earned at institutions other than Washington University may be applied toward the Doctor of Philosophy degree and a maximum of 48 units for the Doctor of Science degree. Transfer credit must be recommended by the adviser, department or program chairman, and be approved by the appropriate registrar. No graduate courses carrying grades lower than B can be accepted for transfer toward any graduate degree.

No courses will be accepted toward degree requirements if the course exceeds the 10-year maximum time period unless they have formal approval of the Engineering Graduate Board.

Disability Resources

Services for students with hearing, temporary or permanent visual, orthopedic, learning or other disabilities are coordinated through Disability Resources (DR). Identifying oneself as having a disability is voluntary.

To the greatest extent possible, students with disabilities are integrated as equal members of the total student population. Services provided for students with disabilities may include but are not limited to: readers, note takers, special parking, tutoring, counseling, appropriate academic accommodations such as alternate testing conditions, and referral to community resources. To receive accommodations or services, students must initiate a request for services and are encouraged to contact DR upon admission or once diagnosed. For more information please visit the Disability Resources website (<http://cornerstone.wustl.edu/disability-resources>).

Leaves of Absence

Engineering students may petition to take a leave of absence. On a leave of absence, students in good standing are assured re-enrollment within the next two years. Before returning, the student is to notify the School of Engineering & Applied Science and submit a Reinstatement Form at least six weeks prior to the beginning of the appropriate term. A student wishing to take a medical leave of absence must have a recommendation for the medical leave of absence from Habif Health and Wellness Center submitted to the appropriate dean in the School of Engineering & Applied Science prior to leaving and prior to re-enrollment. The dean will decide whether or not to grant the request for the medical leave of absence and re-enrollment upon reviewing the recommendations from Habif Health and Wellness Center and the student's file.

Academic Integrity

All students in the School of Engineering & Applied Science are expected to conform to high standards of conduct. This statement on student academic integrity is intended to provide guidelines on academic behaviors which are not acceptable.

It is dishonest and a violation of academic integrity if:

1. A student turns in work which is represented as theirs when in fact they have significant outside help. When they turn in work with their name on it, they are in effect stating that the work is theirs, and only theirs.
2. A student uses the results of another person's work (exam, homework, computer code, lab report) and represent it as their own, regardless of the circumstances.
3. A student requests special consideration from an instructor when the request is based upon false information or deception.
4. A student submits the same academic work to two or more courses without the permission of each of the course

instructors. This includes submitting the same work if the same course is retaken.

5. A student willfully damages the efforts of other students.
6. A student uses prepared materials in writing an in-class exam except as approved by the instructor.
7. A student writes on or make erasures on any test material or class assignment being submitted for re-grading.
8. A student collaborates with other students planning or engaged in any form of academic dishonesty.
9. A student turns in work, which is represented as a cooperative effort, when in fact they did not contribute their fair share of the effort.
10. A student does not use proper methods of documentation. For example, students should enclose borrowed information in quotation marks; acknowledge material that they have abstracted, paraphrased or summarized; cite the source of such material by listing the author, title of work, publication, and page reference.

This list is not intended to be exhaustive. To seek clarification, students should ask the professor or assistant in instruction for guidance.

Note: PhD students should refer to the Graduate School Policies and Procedures webpage (<http://graduateschool.wustl.edu/policies-procedures>) for a link to the full text of the Academic and Professional Integrity Policy for Graduate Students.

Financial Information

Tuition Policy

The 2018-19 tuition and fees (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/tuition-financial-assistance.aspx>) for graduate students in the School of Engineering & Applied Science can be found on the Engineering graduate admissions webpage. Tuition for full-time students is determined by each student's prime division, not by the division that teaches the course. Students should check with their department before enrolling in courses outside their division.

Students who will receive reimbursement from their employers are responsible for tuition being paid by the due date. Employer reimbursements that are contingent upon course completion and/or a satisfactory grade will not exempt the student from stated due dates and the assessment of penalties.

All **full-time** students in Engineering (DSc and master's) are assessed tuition at a full-time tuition rate and do not receive refunds for dropping individual courses. All **part-time** graduate students who were assessed tuition on a per credit hour basis may receive a refund for dropped course(s) based on the refund schedule below. Refunds are computed from the date on which the course is dropped, as reflected in the Student Information

System. Refund checks are made available as soon as possible (usually 4-6 weeks after the drop is completed).

Period of Withdrawal	Percent of Refund
1st-2nd week of classes	100%
3rd-4th week of classes	80%
5th-6th week of classes	60%
7th-8th week of classes	50%
9th-10th week of classes	40%
After 10th week of classes	No Refund

Note: After the date of the first class meeting, refunds are not granted for **short courses** which run less than the full semester length. Questions concerning the refund policy should be directed to the Engineering Accounting Office at 314-935-6183.

Financial Aid

Master's students are expected to be self-supporting and are generally not eligible for any institutional financial assistance. However, participants in the Bachelor's/Master's Program (<https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/bs-ms.aspx>) and the Dual Degree Program (<https://engineering.wustl.edu/prospective-students/dual-degree/Pages/masters-degree-programs.aspx>) could qualify for tuition remission. All master's students who attend at least half-time (3 units in the summer and 4.5 units in the fall and spring) and are U.S. citizens or permanent residents may be eligible for federal student loans.

Federal financial aid for PhD students is processed by the Graduate School. Candidates should complete the Free Application for Federal Student Aid (FAFSA (<https://fafsa.ed.gov>)) for the appropriate academic year. For more information, contact:

Amy Gassel
Email (agassel@wustl.edu)
Phone: 314-935-6821

Loans

The federal government provides a number of student loan programs with rules and requirements for each program. These are subject to change by the government agency overseeing the program and require that detailed financial information be provided by the student. For more information on federal loans (<https://engineering.wustl.edu/prospective-students/Pages/GradFinAddApp.aspx>) available to graduate students please visit the Engineering website.

Interdisciplinary Opportunities

Washington University offers courses through Interdisciplinary Programs that include studies in a variety of disciplines that cross traditional academic boundaries and support academic areas outside the schools.

- A limited opportunity for some Washington University students to enroll in courses at Saint Louis University and the University of Missouri-St. Louis is available through the Inter-University Exchange Program (p. 104).
- The Skandalaris Center (p. 105) offers co-curricular programming and practical, hands-on training and funding opportunities to students and faculty in all disciplines and schools.

Inter-University Exchange Program

The Inter-University Exchange (IE) program between Washington University, Saint Louis University (SLU) and the University of Missouri-St. Louis (UMSL) began in 1976 as an exchange agreement encouraging greater inter-institutional cooperation at the graduate level. Over time, this program has evolved to include undergraduate education; however, the basic provisions of the original agreement are still in place today, and participation continues to be at the discretion of each academic department or unit.

At Washington University, there are several schools that **do not participate** in this program (i.e., degree-seeking students in these schools are not eligible to participate in the IE program, and courses offered in these schools are not open to SLU and UMSL students attending Washington University through the IE program). They are the School of Law, the School of Medicine, University College and the Summer School. The Washington University schools that are open to participation in the Inter-University Exchange program may have specific limitations or requirements on participation; details are available in those offices.

The following provisions apply to all course work taken by Washington University students attending Saint Louis University or the University of Missouri-St. Louis through the Inter-University Exchange program:

- Such courses can be used in the fulfillment of degree or major requirements. (Students should consult with their dean's office for information about how IE course work will count toward GPA, units, and major requirements.)
- Such courses are not regularly offered at Washington University.

- Registration for such courses requires preliminary approval of the student's major/department adviser, the student's division office or dean, and the academic department of the host university.
- Students at the host institution have first claim on course enrollment (i.e., a desired course at SLU or UMSL may be fully subscribed and unable to accept Washington University students).
- Academic credit earned in such courses will be considered as resident credit, not transfer credit.
- Tuition for such courses will be paid to Washington University at the prevailing Washington University rates; there is no additional tuition cost to the student who enrolls in IE course work on another campus. However, students are responsible for any/all fees charged by the host school.
- Library privileges attendant on enrolling in a course on a host campus will be made available in the manner prescribed by the host campus.

Instructions

Washington University students must be enrolled full-time in order to participate in the IE program and have no holds, financial or otherwise, on their academic record at Washington University or at the host institution.

1. The student must complete the Inter-University Exchange application form. Forms are available from the Office of the University Registrar and on its website (link below).
2. The student must provide all information requested in the top portion of the form and indicate the course in which they wish to enroll.
3. The student must obtain the approval signature of the professor teaching the class (or department chair) at SLU or UMSL, preferably in person.
4. The student also must obtain approval signatures of their major adviser at Washington University and the appropriate individual in their dean's office.
5. Completed forms must be submitted to the Office of the University Registrar in the Women's Building a minimum of one week before the start of the term.

Course enrollment is handled administratively by the registrars of the home and host institutions. Washington University students registered for IE course work will see these courses on their class schedule and academic record at WebSTAC under departments 197 (SLU) and 198 (UMSL). Final grades are recorded when received from the host institution. The student does not need to obtain an official transcript from SLU or UMSL to receive academic credit for IE course work at Washington University.

Contact: Office of the University Registrar
Phone: 314-935-5959
Email: registrar@wustl.edu
Website: <http://registrar.wustl.edu/student-records/registration/the-inter-university-exchange-program>

Skandalaris Center for Interdisciplinary Innovation and Entrepreneurship

The Skandalaris Center for Interdisciplinary Innovation and Entrepreneurship (<http://skandalaris.wustl.edu>) is the place on campus *Where Creative Minds Connect*.

Mission

The Skandalaris Center aims to inspire and develop **creativity, innovation, and entrepreneurship** at Washington University in St. Louis.

Who We Serve

Our initiatives serve all Washington University students, alumni, faculty, and staff and sometimes the community. We call this the **SC Network**.

Our Initiatives

Our initiatives are divided into three parts:

1. **Get Connected** (p. 105)
2. **Get Trained** (p. 105)
3. **Get Funded** (p. 105)

Get Connected

A great way to get started in creativity, innovation, and entrepreneurship at Washington University is to get connected with peers and various resources:

Join a Student Group or Fellowship

There are 14 student organizations committed to various aspects of creativity, innovation, and entrepreneurship. Some are limited to undergraduate or graduate student participation, and some support all.

Visit our Student Organizations (<https://skandalaris.wustl.edu/get-connected/student-orgs>) webpage.

Join the Skandalaris Center Email List

The email newsletter is the most up-to-date and complete record of upcoming opportunities.

Join the email list (<https://skandalaris.wustl.edu/get-connected/stay-connected-with-skandalaris>).

Get Trained

The Skandalaris Center offers many programs that provide real-world, practical training in creativity, innovation, and entrepreneurship. Below are a few program examples:

1. **InSITE Fellowship** (<http://skandalaris.wustl.edu/training/insite-fellowship>)
The InSITE Fellowship is a prestigious fellowship available to graduate students who demonstrate a passion and drive for innovation, entrepreneurship, and/or venture capital. A nationally recognized fellowship, this is an opportunity for graduate students in all schools to work with local entrepreneurs and venture capitalists (VCs) on consulting projects. In addition to connecting with local startups and VCs, fellows will have the opportunity to attend national conferences, including SXSW, and host networking events on campus.
Washington University is among peer schools such as Stanford, MIT, Harvard, NYU, Columbia, and University of Pennsylvania, as it is one of the first schools in the Midwest, along with University of Chicago, to launch the InSITE Fellowship.
2. **Meet & Eats** (<https://skandalaris.wustl.edu/training/meet-eats>)
"Meet & Eats" are irregularly occurring talks intended to help expose students to a variety of creators, innovators, and entrepreneurs. The topic and/or industry changes every time, but one thing remains consistent: We buy you food!
3. **Hatchery** (<http://skandalaris.wustl.edu/training/hatchery>)
Various schools at Washington University offer entrepreneurial training for credit. One such course is The Hatchery (Business Planning for New Enterprises). It is offered by the Olin Business School in both the fall and spring semesters and is open to all students at the university.
Students form teams around a commercial or social venture idea proposed by a student or community entrepreneur. The deliverables for the course include two presentations to a panel of judges and a complete business plan. The deliverables in the course are similar to the deliverables in the Skandalaris Center's business plan competitions and can be a valuable first step toward competitions and funding for a new venture.

Get Funded

The Skandalaris Center offers three business plan competitions for the Washington University community:

LEAP Inventor Challenge (<https://skandalaris.wustl.edu/funding/leap>)

The LEAP Inventor Challenge awards funding to those with translational research and inventions with the goal of advancing

Washington University in St. Louis's intellectual property toward commercialization.

- **Who Can Apply:** Washington University faculty, postdoc, graduate student, and staff research teams
- **Award:** Award amounts vary

The Skandalaris Center Cup (SC Cup) (<http://skandalaris.wustl.edu/funding/sc-cup>)

The SC Cup provides expert mentorship to scalable, for-profit ventures to ready them for commercializing their idea, launching, and pitching to investors.

- **Who Can Apply:** Washington University students, postdocs, and recent alumni
- **Award:** Up to \$5K, six months of mentorship

Suren G. Dutia and Jas K. Grewal Global Impact Award (GIA) (<http://skandalaris.wustl.edu/funding/global-impact-award>)

GIA awards scalable, impactful, quick-to-market Washington University-affiliated startups.

- **Who Can Apply:** Washington University students, postdocs, residents, and recent alumni
- **Award:** Up to \$50K

Learn More

Please contact the Skandalaris Center (<https://skandalaris.wustl.edu/contact-us>) for additional information about all programs. We're excited to hear from you!

Contact: Jessica Stanko
Phone: 314-935-9134
Email: sc@wustl.edu
Website: <http://skandalaris.wustl.edu>

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