2019-20 Bulletin

McKelvey School of Engineering 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; Business; Engineering; 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 *2019-20 Bulletin* is 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 the full PDF, please choose from the following:

- Architecture & Urban Design Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_grad_architecture.pdf)
- Art Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_grad_art.pdf)
- Arts & Sciences Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_graduate_school.pdf)
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- Engineering Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_grad_engineering.pdf)
- Law Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_law.pdf)
- Medicine Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_medicine.pdf)
- Social Work & Public Health Bulletin (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_brownschool.pdf)
- University College Bulletin (undergraduate & graduate) (PDF) (http://bulletin.wustl.edu/grad/Bulletin_2019-20_university_college.pdf)

The degree requirements and policies in the *2019-20 Bulletin* apply to students entering Washington University during the 2019-20 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 25, 2019). 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 the Bulletin editor (bulletin_editor@wustl.edu) with any questions concerning the *Bulletin.*

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 it 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 to protect the freedom of inquiry through research, teaching and learning.

Washington University creates an environment that encourages and supports 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 as follows:

- 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 the 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 do the following:

- 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 2019

Date	Day	Description
August 26	Monday	Classes begin
September 2	Monday	Labor Day holiday
October 12-15	Saturday-Tuesday	Fall Break
November 27-December 1	Wednesday-Sunday	Thanksgiving Break
December 6	Friday	Last day of classes

December 9-18	Monday-Wednesday	Reading and Exams

Spring Semester 2020

Date	Day	Description
January 13	Monday	Classes begin
January 20	Monday	Martin Luther King Jr. holiday
March 8-14	Sunday-Saturday	Spring Break
April 24	Friday	Last day of classes
April 27-May 6	Monday-Wednesday	Reading and Exams
May 15	Friday	Commencement

Summer Semester 2020

Date	Day	Description
May 18	Monday	First Summer Session begins
May 25	Monday	Memorial Day holiday
July 3	Friday	Independence Day holiday
August 13	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

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 Learning Center website (https://learningcenter.wustl.edu) or call 314-935-5970. There are three types of services housed within the Learning Center:

- **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 as well as course-specific weekly walk-in sessions facilitated by academic mentors in locations, at times and in formats convenient for the students. The Learning Center also offers individual consulting/coaching for academic skills such as time management, study skills, note taking, accessing resources and so on. 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 (https://students.wustl.edu/disability-resources) or contact 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, who are the first in their family to go to college, and/or who 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 they enter their first semester. Eligible students are encouraged to apply when they are notified, because space in this program is limited. For more information, visit the TRIO Program website (https://students.wustl.edu/trio-program).

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

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 their orientation programs, issue certificates of eligibility (visa documents), and provide visa and immigration information. 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 on the Danforth Campus in the Danforth University Center at 6475 Forsyth Boulevard, Room 330. The office can be found on the Medical Campus in the Mid Campus Center (MCC Building) at 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.

Office of Military and Veteran Services is located in Umrath Hall on the Danforth Campus. This office serves as the university's focal point for military and veteran matters, including transitioning military-connected students into higher education, providing and connecting students with programs and services, and partnering across campus and in the community. Services include advising current and prospective students on how to navigate the university and maximize Department of Defense and Veterans Affairs (VA) educational benefits, transition support, Veteran Ally training for faculty and staff, veteran-unique programming, and connecting students to campus and community resources. Military-connected students include veterans, military service members, spouses, dependent children, caregivers, survivors and Reserve Officer Training Corp cadets. There are two university policies that apply to students who still serve in the Armed Forces and students who use VA educational benefits:

- The Policy on Military Absences, Refunds and Readmissions (https://veterans.wustl.edu/policies/policy-for-military-students) applies to students serving in the U.S. Armed Forces and their family members when military service forces them to be absent or withdraw from a course of study.
- The Policy on Protections for VA Educational Benefit Users (https://veterans.wustl.edu/policies/policy-for-va-students) applies to students using VA education benefits when payments to the institution and the individual are delayed through no fault of the student.

Please visit the Military and Veteran Services website (https://veterans.wustl.edu) or contact Military and Veteran Services at 314-935-2609 or veterans@wustl.edu for more information.

Relationship and Sexual Violence Prevention (RSVP) Center. The RSVP Center offers free and confidential services including 24/7 crisis intervention, counseling services, resources, support and prevention education for all students on the Danforth Campus. The RSVP Center operates from a public health model and uses trauma-informed practices to address the prevalent issues of relationship and sexual violence. By providing support for affected students, it is our goal to foster post-traumatic growth and resilience and to help ensure academic retention and success. Our prevention efforts call for community engagement to engender an intolerance of violence and an active stance toward challenging cultural injustices that perpetuate such issues. Learn more at the RSVP Center website (https://rsvpcenter.wustl.edu).

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

The Writing Center is located in Olin Library on Level 1. Appointments (http://writingcenter.wustl.edu) are preferred and can be made online.

Student Health Services, Danforth Campus

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 Dardick House on the South 40 or the Habif Health and Wellness Center website (http://shs.wustl.edu) for more information about Habif's 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 and after hours mental health crisis line are available to answer any medical or mental health 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, immunizations, nutrition counseling, physical therapy, and travel medicine and sexual health services. Habif Health and Wellness Center providers 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 specialist. Habif accepts most health insurance plans and will be able to bill the plan according to plan benefits. The student health insurance plan requires a referral for medical care any time care is not provided at Habif (except in an emergency). Call 314-935-6666 or visit the Habif website to schedule an appointment (http://shs.wustl.edu).

Appointments are also available for the assessment, treatment, and referral of 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; students should check with the pharmacist to see if their 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 Habif's reference lab, and it is a preferred provider on the student health insurance plan. This lab can perform any test ordered by Habif providers or outside providers.

All incoming students must provide proof of immunization for measles, mumps, and rubella (i.e., two vaccinations after the age of one year old; a titer may be provided in lieu of the immunizations). Proof of receiving a meningococcal vaccine 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 the Habif website. It is also recommended that, during the five years before beginning their studies at Washington University, all students will have received the tetanus diphtheria immunization, the hepatitis A vaccine series, the hepatitis B vaccine series, and the varicella vaccine. Medical History Forms (http://shs.wustl.edu) are available online. Failure to complete the required forms will delay a student's registration and prevent their entrance into housing assignments. Please visit the Habif 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. 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 the Habif website to schedule an appointment (http://shs.wustl.edu).

Health Promotion Services provides free programs and risk reduction information related to issues such as stress, sleep, sexual health and alcohol/other drugs. For more information, visit the Zenker Wellness Suite in Sumers Recreation Center to learn about the programs on campus led by student peer health educators. Call 314-935-7139 or send an email to wellness@wustl.edu for more information.

In 2018, this department launched the **WashU Recover Group** to provide an opportunity for students in recovery from substance use to connect with other students with similar experiences. The group provides local resources, support, meetings and activities. Members have 24/7 access to a private facility to study, meet and socialize. The group is not a recovery program; it is a confidential resource that students can add to their support system. For more information, send an email to recovery@wustl.edu.

Important Information About Health Insurance, Danforth Campus

Washington University has a student health fee that was 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 they provide 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 provides 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 the students' 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 it enjoys a safe and 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, the 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 and 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 and a mobile Campus Circulator shuttle 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 every 30 minutes 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 in real time using the WUSTL Mobile App. The app can be downloaded free of charge from the Apple 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 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, and security surveys. Community members are encouraged to download and install the personal safety app Noonlight on their phones; this app allows users to call for help during emergencies. For more information about these programs, visit the Washington University Police Department website (https://police.wustl.edu/Pages/Home.aspx).

In compliance with the Campus Crime Awareness and Security Act of 1990, Washington University publishes an annual report (http://police.wustl.edu/clerylogsandreports/Pages/default.aspx) entitled *Safety & Security: Guide for Students, Faculty, and Staff — Annual Campus Security and Fire Safety Reports and Drug & Alcohol Abuse Prevention Program*. This report 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; it 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 the following individuals:

Discrimination and Harassment Response Coordinator

> Apryle Cotton, Assistant Vice Chancellor for Human Resources
> Section 504 Coordinator
> Phone: 314-362-6774
> apryle.cotton@wustl.edu

Title IX Coordinator

> Jessica Kennedy, Director of Title IX Office
> Title IX Coordinator
> Phone: 314-935-3118
> 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; by visiting the U.S. Department of Education website (https://www.ed.gov); or by calling 800-421-3481.

Student Health

Drug and Alcohol Policy

Washington University is committed to maintaining a safe and healthy 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 rgw 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. Students should 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:

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

Violations of This Policy Include but Are Not Limited to the Following:

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 do the following:
   - 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 (i.e., the 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, or 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 do any of the following:
   - 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, 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 the following:
   - 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 do any of the following:
   - 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 rather than 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, an assistant in instruction, an academic integrity officer or another student — is entitled to do the following:

- 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
- Receive a 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 do the following:

- 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 (however, 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 with regard to 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 student's 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 given 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.

In addition, 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://

registrar.med.wustl.edu/services/transcripts-and-certification) accepts requests for transcripts and certification records for students and alumni of Audiology and Communication Sciences, Biomedical Informatics, Biostatistics, Clinical Investigation, Genetic Epidemiology, Health Administration, Health Behavior Research, Nurse Anesthesia, Occupational Therapy, Pediatric Nurse Practitioner, Physical Therapy, Population Health Sciences, Psychiatric Epidemiology, the School of Dentistry and the 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 American Academy of Arts & Sciences, American Association of University Women (AAUW), American Council of Learned Societies (ACLS), American Council on Education (ACE), Association of American Colleges & Universities (AACU), Association of American Universities (AAU), College Board, Council for Higher Education Accreditation (CHEA), Hispanic Association of Colleges & Universities (HACU), Independent Colleges and Universities of Missouri (ICUM), National Association of Independent Colleges and Universities (NAICU), National Council for State Authorization Reciprocity Agreements (NC-SARA), Oak Ridge Associated Universities (ORAU), and the University Research Association (URA).

The College of Arts & Sciences is a member of the American Association of Collegiate Registrars and Admissions Officers (AACRAO), International Center for Academic Integrity (ICAI), National Association of Fellowship Advisors (NAFA), National Association of Advisors for Health Professions (NAAHP), and the Midwest Associate of Pre-Law Advisors (MAPLA).

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), and its Master of Landscape Architecture degree is accredited by the Landscape Architecture Accrediting Board (LLAB).

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

The Olin Business School is a charter member (1921) of the Association to Advance Collegiate Schools of Business International (AACSB).

In McKelvey School of Engineering, 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.

McKelvey School of Engineering

McKelvey School of Engineering 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 who 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

McKelvey School of Engineering
Lopata Hall, Suite 203
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:	engineeringgradadmissions@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 the 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. However, 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 to 48 units of course work and 24 to 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 are formally approved by the Engineering Graduate Board. In addition, 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 McKelvey School of Engineering. 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 McKelvey School of Engineering has its own policy related to the selection of a doctoral committee; therefore, students should consult with their faculty adviser regarding the appointment of their doctoral committee.

Doctoral Qualifying Examination

To be admitted to candidacy for a doctoral degree, the 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 the student 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 the program director.

Doctoral Dissertation

Doctoral candidates must submit a satisfactory dissertation that involves independent creative work in an area of specialization and that 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 that is the subject of the dissertation must have been performed under the supervision of a member of the faculty of McKelvey School of Engineering. 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 about 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) 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 that embodies the principal findings of the research and that has been approved by the doctoral committee as ready for publication. Such an 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 MS programs are better prepared to move forward to doctoral programs, as they often become more involved in research experience. However, MS 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 who wish 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 minimum requirement stated previously. 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 MS degree under the 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. For a full set of submission instructions, please visit our Graduate Student Services website (https://engineering.wustl.edu/current-students/student-services/Pages/thesis-dissertation-submissions.aspx).

Master's Final Examinations

The final examination for the MS 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 MS 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

For additional graduate programs, please visit the Henry Edwin Sever Institute (p. 86) 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 from the molecular level to the whole-body level. 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 include 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 two to four semesters.

Students seeking the **Master of Engineering (MEng) in Biomedical Innovation** will complete an immersive 12-month medical technology entrepreneurial experience that culminates in their own intellectual property, which is 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 they are also ready to contribute to teaching and research translation. The **MD/PhD in Biomedical Engineering,** which is offered 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

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

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

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

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

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

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 our graduate programs:

- Postdoctoral Medical Physics Certificate (p. 24)
- PhD and Combined MD/PhD in Biomedical Engineering (p. 24)
- Master of Science (MS) in Biomedical Engineering (p. 25)
- Master of Engineering (MEng) in Biomedical Innovation (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 you 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 or 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 will 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 will 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. Prerequisites: 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; and the cytoskeleton, the extracellular matrix, and cell movement. Emphasis will be placed on examples relevant to biomedical engineering. The course will include two lectures per week and one discussion section. In the discussion section, the emphasis will be on experimental techniques used in cell biology and the critical analysis for primary literature. Note that 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 Biol 2970 or graduate standing.
Credit 4 units.

E62 BME 532 Physics of Biopolymers and Bioinspired Polymers
This course will cover physics concepts from the statistical physics of polymers and polymer solutions to describe proteins, nucleic acids, and bioinspired polymers. Topics include statistical physics concepts, theoretical and numerical descriptions of polymers, applying these descriptions to biopolymers, the thermodynamics of polymer solutions, concepts of polymer dynamics, descriptions of polymeric materials and advanced topics in phase transitions and molecular design. The material will be fast-paced and involve rigorous mathematical descriptions, experimental design, interpretations of experimental data, and some numerical simulations. The course will be heavy on individual homework and team-based project work. Direct connections between concepts and modern topics in biology and biomaterials will be emphasized. Prerequisites: BME 320B or equivalent and a first course in transport phenomena.
Same as E62 BME 432
Credit 3 units. EN: TU

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 the discovery of gene regulatory networks, the quantitative modeling of gene regulatory networks, synthetic biology, and (in some years) the quantitative modeling of metabolism. Prerequisite: CSE 131 or CSE 501N.
Same as E81 CSE 587A
Credit 3 units. EN: TU

E62 BME 538 Cell Signal Transduction
This course will cover the elements of cell signal transduction important to human development, homeostasis and disease. Lectures will be combined with primary literature review to cover canonical signaling and current topics within the field. Spatial, time and dose-dependent aspects of signaling will be 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 542 Biomacromolecules Design and Engineering
Biological macromolecules (i.e., carbohydrates, lipids, proteins, and nucleic acids) are important components of the cell and its supporting matrix that perform a wide array of functions. This course will introduce the principles and recent advances in nucleic acid/gene engineering, protein/peptide engineering, and chemical/enzymatic conjugation technologies; it will also discuss the application of engineered biomacromolecules in clinical therapeutics/diagnostics, biosensing, bioimaging, and biocatalysis. Students will learn material through lecture, reading, homework, scientific publications, and molecular visualization tools. Students will work individually or in pairs/groups to develop and lead discussions on engineering biomacromolecules and molecular characterization techniques. Prerequisites: basic knowledge of genes and cloning.
Same as E62 BME 442
Credit 3 units. EN: TU

E62 BME 543 Molecular and Cellular Engineering
The ability to engineer biological function at the cellular level holds tremendous potential for both basic and applied science. This course aims to provide knowledge and practical proficiency in the methods available for measuring and controlling the molecular organization of eukaryotic cells. Topics to be covered include genome engineering using viral- and CRISPR-Cas systems; spatial and temporal control of proteins and their interactions; methods for characterizing and engineering post-translational modifications; and the relationship between cellular organization and function in migration, immune cell target recognition, and differentiation. Examples from recent scientific literature will provide the foundation for these topics.
Same as E62 BME 443
Credit 3 units. EN: TU

E62 BME 544 Biomedical Instrumentation
This course will include operational and instrumentation amplifiers for bioelectric event signal conditioning, interfacing, and processing; instrumentation noise analysis and filter design; A/D converters and hardware and software principles as related to sampling, storing, processing, and display of biosignals; modeling, analysis, and operation of transducers, sensors, and electrodes for physiological and imaging systems; and an introduction to ultrasound, X-ray, and optical imaging systems. In addition, students will be involved in three projects of designing and building instrumentation amplifier and filter systems, ultrasound systems, and optical systems. Prerequisites: BME 301A and BME 301B.
Same as E62 BME 444
Credit 3 units. EN: TU

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: BME T, 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 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: BME T, 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 570 Mathematics of Imaging Science
This course will expose students to a unified treatment of the mathematical properties of images and imaging. This will include an introduction to linear vector space theory, operator theory on Hilbert spaces, and concepts from applied functional analysis. Further, concepts from generalized functions, Fourier analysis, and Radon transform will be discussed. These tools will be applied to conduct deterministic analyses of imaging systems that are described as continuous-to-continuous, continuous-to-discrete, and discrete-to-discrete mappings from object properties to image data. In addition, imaging systems will be analyzed in a statistical framework where stochastic models for objects and images will be introduced. Prerequisite: senior standing or instructor permission.
Credit 3 units.

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, design, and application of modern optical imaging systems, with emphasis on biological imaging. The first part of the 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). The second part of the 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: BME T, 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: BME T, 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: BME T, TU

E62 BME 5902 Cellular Neurophysiology
This course will examine the biophysical concepts of synaptic function, with a 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, and models of synaptic disease states such as Parkinson's and Alzheimer's diseases. In addition, a set of lectures will be devoted to modern electrophysiological and imaging techniques as well as modeling approaches to study synapses and neural circuits. Prerequisite: senior or graduate standing.
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 of identifying 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 594 Ultrasound Imaging
This course will 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

Postdoctoral Medical Physics Certificate

Students seeking the **Postdoctoral Medical Physics Certificate** must complete 18 course credits, which can be completed in 2 to 4 semesters. A Medical Physics Certificate allows a student with a PhD in physics or another related subject to apply for medical physics residency programs and to 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/

PhD and Combined MD/PhD in Biomedical Engineering

The department offers programs that lead to the Doctor of Philosophy (PhD) in Biomedical Engineering as well as combined MD/PhD degrees. The latter degrees are conferred 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 an approved list
- One graduate-level course in computer science from an 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 and/or BME 501C Graduate Seminar may be counted toward the 36 credits of graduate courses required for the PhD, so a total of 27 additional credits (usually 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 during the first year. Ten months after they enroll in the program, students take their oral qualifying exam, which consists 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 preclinical 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.

Master of Science (MS) in Biomedical Engineering

The 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 core and approved courses.

Candidates for the MS must accumulate a total of 30 graduate course credits beyond the bachelor's degree. Only 6 of these 30 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 requirements; courses can be 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 GPA of 2.7 or better, and satisfy the core curriculum requirement (courses can be 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 or another type of health care company or for running their own startup. It is a team-based approach in which students develop the engineering, design and business skills needed 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 57XX 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.

Computational & Data Sciences

The Division of Computational & Data Sciences (DCDS) at Washington University in St. Louis trains students interested in problems from across a range of disciplines that share a common reliance on data and computing.

The introduction of now-standard tools from statistical analysis and hypothesis testing transformed the practice of natural and social science in the mid-20th century. Emerging tools from computational and data science have the potential to bring about an even larger transformation of scientific practice, especially in the social sciences. The questions raised by data generated by and about human behavior are engaging and profound. However, many if not most of these questions can only be tackled using a multidisciplinary approach that combines a deep knowledge of the capabilities and operation of data science techniques with the domain expertise needed to apply them effectively to the problems under consideration.

Doctoral students in Computational & Data Sciences receive strong methodological training in modern computational and statistical methods, and they also acquire expertise in a particular social science application area.

The program is inherently interdisciplinary and brings together leading experts from across the university who are using data to solve some of the greatest challenges that our world faces today. Faculty include both data and computing experts as well as domain experts from different application areas.

Faculty

Deanna Barch (https://psych.wustl.edu/people/deanna-barch)
Professor and Chair, Psychological & Brain Sciences
PhD, University of Illinois

Michael Bechtel (https://artsci.wustl.edu/faculty-staff/michael-m-bechtel)
Associate Professor, Political Science
PhD, University of Konstanz

Ryan Bogdan (https://psych.wustl.edu/people/ryan-bogdan)
Associate Professor, Psychological & Brain Sciences
PhD, Harvard University

Todd Braver (https://psych.wustl.edu/people/todd-braver)
Professor, Psychological & Brain Sciences, Radiology, and Neuroscience
PhD, Carnegie Mellon University

Derek Brown (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Derek-Brown.aspx)
Associate Professor, Brown School
PhD, Duke University

Sanmay Das (https://engineering.wustl.edu/Profiles/Pages/Sanmay-Das.aspx)
Track Chair, Computational Methodologies
Associate Professor, Computer Science & Engineering
PhD, Massachusetts Institute of Technology

Brett Drake (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Brett-Drake.aspx)
Professor, Brown School
PhD, UCLA

Christine Ekenga (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Christine-Ekenga.aspx)
Assistant Professor, Brown School
PhD, New York University

Patrick Fowler (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Patrick-Fowler.aspx)
Track Chair, Social Work & Public Health
Associate Professor, Brown School
PhD, Wayne State University

Roman Garnett (https://engineering.wustl.edu/Profiles/Pages/Roman-Garnett.aspx)
Assistant Professor, Computer Science & Engineering
PhD, University of Oxford

Chris Gill (https://engineering.wustl.edu/Profiles/Pages/Christopher-Gill.aspx)
Professor, Computer Science & Engineering
DSc, Washington University in St. Louis

Roch Guérin (https://engineering.wustl.edu/Profiles/Pages/Roch-Gu%C3%A9rin.aspx)
Professor and Chair, Computer Science & Engineering
PhD, California Institute of Technology

Shenyang Guo (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Shenyang-Guo.aspx)
Professor, Brown School
PhD, University of Michigan - Ann Arbor

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PhD, University of Michigan

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PhD, Saint Louis University

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PhD, University of California, Los Angeles

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Professor of Practice, Brown School
PhD, Michigan State University

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Associate Professor, Psychological & Brain Sciences
PhD, University of Illinois, Urbana-Champaign

Kim Johnson (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Kimberly-Johnson.aspx)
Associate Professor, Brown School
PhD, University of Minnesota

Melissa Jonson-Reid (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Melissa-Jonson-Reid.aspx)
Professor, Brown School
PhD, University of California, Berkeley

Brendan Juba (https://cse.wustl.edu/faculty/Pages/faculty.aspx?bio=37)
Assistant Professor, Computer Science & Engineering
PhD, Massachusetts Institute of Technology

Caitlin Kelleher (https://engineering.wustl.edu/Profiles/Pages/Caitlin-Kelleher.aspx)
Associate Professor, Computer Science & Engineering
PhD, Carnegie Mellon University

Matt Kreuter (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Matthew-Kreuter.aspx)
Professor, Social Work & Public Health
PhD, University of North Carolina, Chapel Hill

Calvin Lai (https://psych.wustl.edu/people/calvin-lai)
Assistant Professor, Psychological & Brain Sciences
PhD, University of Virginia

Christopher Lucas (http://polisci.wustl.edu/faculty/christopher-lucas)
Assistant Professor, Political Science
PhD, Harvard University

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Professor, Brown School
PhD, University of Illinois

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Professor, Political Science and Law
Chancellor-Elect, Washington University in St. Louis
PhD, Washington University in St. Louis

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Professor, Brown School
PhD, University of Wisconsin - Madison

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Track Chair, Political Science
Associate Professor, Political Science
PhD, Duke University

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Assistant Professor, Computer Science & Engineering
PhD, Tufts University

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PhD, Harvard University

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Associate Professor, Political Science
PhD, Duke University

Deborah Salvo (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Deborah-Salvo.aspx)
Assistant Professor, Brown School
PhD, Emory University

Betsy Sinclair (http://polisci.wustl.edu/faculty/betsy-sinclair)
Professor, Political Science
PhD, California Institute of Technology

Joe Steensma (https://brownschool.wustl.edu/Faculty-and-Research/Pages/Joseph-Steensma.aspx)
Professor of Practice, Brown School
EdD, Indiana Wesleyan University

Yevgeniy Vorobeychik (https://engineering.wustl.edu/Profiles/Pages/Yevgeniy-Vorobeychik.aspx)
Associate Professor
Computer Science & Engineering
PhD, University of Michigan

William Yeoh (https://engineering.wustl.edu/Profiles/Pages/William-Yeoh.aspx)
Assistant Professor
Computer Science & Engineering
PhD, University of Southern California

Jeffrey Zacks (https://psych.wustl.edu/people/jeffrey-zacks)
Track Chair, Psychological & Brain Sciences
Professor and Associate Chair, Psychological & Brain Sciences
PhD, Stanford University

Degree Requirements

PhD in Computational & Data Sciences

Upon joining the PhD program, each student is assigned an initial adviser from the DCDS faculty. This adviser meets with the student to assess their background and to advise them on course selection. Immediately prior to each fall semester (starting in 2019), DCDS faculty conduct a “boot camp” in mathematics, statistics and programming to help bring incoming students up to the level needed to succeed in the initial course work and the program.

All students complete a common core curriculum as well as a domain depth requirement in a social science area. The focus of the first year is on acquiring a common set of tools and an understanding of the ranges and types of problems students may work on as they progress through the program. The entire incoming cohort takes a unique two-semester seminar sequence solely for DCDS students, which includes both general topics and a series of data-driven dives into the types of research questions that may be encountered in each of the domain areas.

In addition, students will be exposed to research in different areas through “rotations” that start in November of their first year. By the end of the summer following their first year, each student will put together an advisory committee of at least two DCDS faculty members (preferably from different tracks) and identify the specific track in which they plan to do research and pursue their degree.

Curriculum

Required Core Courses (24 credit hours)

- **CSE 502 (3 credits):** This is an existing fundamental course in algorithms and data structures, including significant implementation in an object-oriented programming language (currently Java). We expect that many students will already have this background; the course is intended as a pathway for students with very little computational training.

- **Quantitative Methods (QM) I and II (6 credits):** This two-semester sequence covers essential probability and statistics, including hypothesis testing, inference and experimental methodology using a modern statistical computing language like R. The introductory courses offered by the departments of Psychological & Brain Sciences (PBS 5066) and Political Science (PS 581) will be cross-listed and count for QM I credit. QM II is a course that includes maximum-likelihood methods, Bayesian and nonparametric models, generalized linear models and sampling techniques. The course is currently taught as Political Science 582 and will be cross-listed across participating departments.
- **CSE 5XX: "Data Wrangling":** We are in a new era in terms of the volume and modalities of data generated by efforts to measure human behavior. This will be a new cross-listed course that introduces students to the tools and techniques used to collect, maintain and process large-scale data sets of the kind generated in the course of studying people and social systems.
- **Machine Learning I and II: CSE 417T and 517A (3 credits):** This is a two-semester sequence in machine learning. Together, the two courses cover the fundamental principles of supervised learning, including generalization, overfitting, regularization, cross-validation, model selection, core ML techniques and algorithms, including linear models like logistic regression, gradient descent, tree-based and ensemble methods, kernel methods, deep neural networks and topics in unsupervised learning.
- **Computational and Data Sciences (CDS) Seminar I and II (6 credits):** This two-semester seminar sequence is cross-listed across participating departments and team-taught by participating faculty.
  - CDS Seminar I will be structured around topics and ideas that do not need detailed specific-content background. The topics covered will include ethics, the nature of research, robustness and reproducibility of research, and presentations from across the different areas of interest to give students an understanding of research in human and social data analytics across the university.
  - CDS Seminar II will be structured as a series of deep dives into data-driven approaches in each of the domain areas, including a module on computational methodologies. In each of these modules, the students will either be given a specific data set to investigate or a specific hands-on task to complete (e.g., developing a visualization, assessing how easy a computational tool is for social scientists to use). Students will work in teams on these projects.

Domain Depth Tracks

Students will choose one of four focus tracks: Political Science, Psychological & Brain Sciences, Social Work & Public Health, or Computational Methodologies. Depending on the track, students must complete the following domain depth requirements:

1. **Political Science track:** Students must complete three substantive classes in one subfield (e.g., American politics, comparative politics, international relations) from a specified list for each subfield as well as a research design course (PS 540).
2. **Psychological & Brain Sciences track:** Students must complete three substantive classes in one subfield (e.g., brain, behavior and cognition, clinical science, social/personality, development and aging). With permission, students may substitute the Psychological & Brain Sciences Research Methods Course (PBS 5011) for one of the substantive classes, depending on their background in psychological science.
3. **Social Work & Public Health track:** Students must complete a three-course core doctoral seminar series, including conceptual foundations of social science, advanced research methods, and a theory seminar, either in public health or social work. Students will also be required to take an advanced substantive course from an approved list in their area of interest.
4. **Computational Methodologies track:** Students must take CSE 541T Advanced Algorithms and either CSE 511A Introduction to Artificial Intelligence or CSE 515T Bayesian Methods in Machine Learning. In addition, students must take two substantive classes in their area of interest (i.e., political science, psychological & brain sciences, or social work & public health) from among the classes acceptable for students in that track as noted above.

Sample Curriculum

A typical progression of classes is described below, with separate examples for students who enter with and without more extensive computational backgrounds.

Students Without Much Computer Science Background

	Units		
	Fall	**Spring**	**Summer**
First Year			
Data Structures and Algorithms (CSE 502N)	3	—	—
Quantitative Methods I	3	—	—
CDS Seminar I	3	—	—
Introduction to Machine Learning (CSE 417T)	—	3	—
Data Wrangling	—	3	—

CDS Seminar II	—	3	—
	9	**9**	**0**
Second Year			
Quantitative Methods II	3	—	—
Domain course	3	3	—
Domain course or elective	3	3	—
Machine Learning (CSE 517A)	—	3	—
	9	**9**	**0**

Students With More Computer Science Background

	Units		
	Fall	**Spring**	**Summer**
First Year			
Introduction to Machine Learning (CSE 417T) or domain course	3	—	—
Quantitative Methods I	3	—	—
CDS Seminar I	3	—	—
Introduction to Machine Learning (CSE 417T) or domain course	—	3	—
Data Wrangling	—	3	—
CDS Seminar II	—	3	—
	9	**9**	**0**
Second Year			
Quantitative Methods II	3	—	—
Domain course	3	3	—
Domain course or elective	3	3	—
Machine Learning (CSE 517A)	—	3	—
	9	**9**	**0**

Further Requirements

Additional requirements for this program are as follows:

- A minimum of 72 credit hours beyond the bachelor's level, with a minimum of 37 being course credits (including the core curriculum)
- A minimum of 24 credit hours of doctoral dissertation research
- Students must maintain a cumulative average grade of B (3.0 grade-point average) for all 72 credit hours.
- Required courses must be completed with no more than one grade below a B-.
- Up to 24 graduate credit hours may be transferred with the approval of the Graduate Studies Committee, chaired by the director of graduate studies.

In addition to fulfilling the course and research credit requirements, students must do the following:

- Complete at least two three-month-long research rotations.
- Pass a qualifying exam.
- Successfully defend a thesis proposal.
- Present and successfully defend a dissertation.
- Complete a teaching requirement consisting of two semesters of mentored teaching experience.

Computer Science & Engineering

During the past two decades, society has experienced unprecedented growth in digital technology. This revolution continues to redefine our way of life, our culture and our 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 part-time students but that 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 and MS in Computer Engineering degrees only), or it 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, but it is 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 as well as 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 during their first year and the program's emphasis is on creative research. The program has milestones that involve both written and oral components, and these provide structure for 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 backgrounds were outside of the field 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

Neal Patwari (https://engineering.wustl.edu/Profiles/Pages/Neal-Patwari.aspx)
PhD, University of Michigan
Application of statistical signal processing to wireless networks, and radio frequency signals

Weixiong Zhang
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
System security, software security

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

Steve Cole, **Senior Lecturer**
PhD, Washington University in St. Louis
Parallel computing, accelerating streaming applications on GPUs

Marion Neumann (https://cse.wustl.edu/faculty/Pages/Marion-Neumann.aspx)**, Senior Lecturer**
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)**, Lecturer**
PhD, Washington University
Computer architecture and memory management

Douglas Shook (https://cse.wustl.edu/faculty/Pages/Doug-Shook.aspx)**, Lecturer**
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
Computer architecture, organization, and embedded systems

Todd Sproull (https://cse.wustl.edu/faculty/Pages/Todd-Sproull.aspx)**, Senior Lecturer**
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

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 computer science and engineering graduate programs:

- PhD in Computer Science or Computer Engineering (p. 39)
- Master of Science (MS) in Computer Science (p. 39)
- Master of Science (MS) in Computer Engineering (p. 40)
- Master of Science (MS) in Cybersecurity Engineering (p. 40)
- Master of Engineering (MEng) in Computer Science and Engineering (p. 41)
- Certificate in Data Mining and Machine Learning (p. 42)

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
Proposal form can be located at https://cse.wustl.edu/undergraduate/PublishingImages/Pages/undergraduate-research/Independent%20Study%20Form%20400.pdf
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
This course involves the study of fundamental algorithms, data structures, and their effective use in a variety of applications. It emphasizes the 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 131.
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 various web frameworks, 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 the 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: BME T, 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: BME T, 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 to 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.
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: BME T, 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 administrated throughout the course to enhance learning. Prerequisites: CSE 247 and ESE 326 (or Math 3200).
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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 Human-in-the-Loop Computation
This course is an exploration of the opportunities and challenges of human-in-the-loop computation, an emerging field that examines how humans and computers can work together to solve problems neither can yet solve alone. 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 human-in-the-loop systems such as crowdsourcing markets, prediction markets, and user-generated content platforms. We will also look into recent developments in the interactions between humans and AIs, such as learning with the presence of strategic behavior and ethical issues in AI systems. Prerequisites: CSE 247, ESE 326, Math 233, and Math 309.
Credit 3 units. EN: TU

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 the "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: BME T, 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: BME T, 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: BME T, 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: BME T, 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 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: BME T, 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: BME T, 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: BME T, TU

E81 CSE 541T Advanced Algorithms
Provides a broad coverage of fundamental algorithm design techniques, with a focus on developing efficient algorithms for solving combinatorial and optimization problems. The topics covered include the review of greedy algorithms, dynamic programming, NP-completeness, approximation algorithms, the use of linear and convex programming for approximation, 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. Prerequisite: CSE 347.
Credit 3 units. EN: BME T, TU

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.
Credit 3 units. EN: BME T, 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, path planning, and the art gallery problem. Prerequisite: CSE 347.
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 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: BME T, 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 (e.g., images, volumes, point clouds) that need to be processed, visualized, and analyzed. This course will focus on a number of geometry-related computing problems that are essential to the knowledge discovery process in various spatial-data–driven biomedical applications. These problems include visualization, segmentation, mesh construction and processing, and shape representation and analysis. The course consists of lectures that cover theories and algorithms as well as a series of hands-on programming projects using real-world data collected by various imaging techniques (e.g., CT, MRI, electron cryomicroscopy). Prerequisites: CSE 247 and CSE 332 (or proficiency in programming in C++, Java, or Python).
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, TU

E81 CSE 557A Advanced Visualization

We are in an era in which 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 or complex data visually to aid comprehension and cognition. In this course, we learn about the state of the art of visualization research and gain hands-on experience with the research pipeline. We also learn how to critique existing work and how to formulate and explore sound research questions. We will cover advanced visualization topics, including user modeling, adaptation, personalization, perception, and visual analytics for non-experts. Prerequisites: CSE 457A or permission of the instructor.
Credit 3 units. EN: BME T, 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/ESE 318 and CSE 247.
Credit 3 units. EN: BME T, 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: BME T, 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), and so on. 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: BME T, 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: BME T, 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, Multiprotocol Label Switching (MPLS), carrier Ethernet, virtual bridging, LAN extension and virtualization using Layer 3 protocols, virtual routing protocols, the "internet of things," data link layer and management protocols for the internet of things, networking layer protocols for the internet of things, 6LoWPAN, RPL, messaging protocols for the internet of things, 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: BME T, TU

E81 CSE 571S Network Security
This course covers principles and techniques in securing computer networks. Real world examples will be used to illustrate the rationales behind various security designs. There are three main components in the course, preliminary cryptography, network protocol security and network application security. Topics include IPSec, SSL/TLS, HTTPS, network fingerprinting, network malware, anonymous communication, and blockchain. The class project allows students to take a deep dive into a topic of choice in network security. Prerequisite: CSE 473S.
Credit 3 units. EN: BME T, 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 the "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: BME T, 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: BME T, TU

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 alignment-free algorithms. 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 or instructor permission.
Credit 3 units. EN: BME T, 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: BME T, TU

E81 CSE 586A Analysis of Imaging Data
This course focuses on an in-depth study of advanced topics and interests in image data analysis. Students will learn about hardcore imaging techniques and gain the mathematical fundamentals needed to build their own models for effective problem solving. Topics of deformable image registration, numerical analysis, probabilistic modeling, data dimensionality reduction, and convolutional neural networks for image segmentation will be covered. The main focus might change from semester to semester. Prerequisites: Math 309, ESE 326, CSE 247.
Credit 3 units.

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. Prerequisite: CSE131 or CSE501N.
Credit 3 units. EN: TU

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 637S Software Security
In this course, students will be introduced to the foundations of software security. They will be exploring different classes of software vulnerabilities, analyzing the fundamental problems behind these vulnerabilities, and studying the methods and techniques to discover, exploit, prevent and mitigate these vulnerabilities. Topics of interest include buffer overflow, integer overflow, type confusion, and use-after-free. Throughout the course, we will take a defense-in-depth mentality and see how systems can be protected. Students are expected to have a solid understanding of assembly language, C/C++, and operating systems. Prerequisite: CSE 361S.
Credit 3 units.

E81 CSE 659A Advances in Computer Vision
This course will describe advanced and modern algorithms for computer vision and pattern recognition applications. We will cover various techniques for modeling images and physical and semantic attribute maps, advanced algorithms for continuous and discrete optimization, and modern learning approaches based on the use of deep convolutional neural networks. Prerequisite: CSE 559A or permission of instructor.
Credit 3 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.

PhD in Computer Science or Computer Engineering

Students can choose to pursue a PhD in Computer Science or a PhD in 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 degree and the PhD in Computer Engineering degree.
- 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 that demonstrate the ability to understand research literature, to communicate orally and in writing, and to formulate a detailed research plan. These milestones include an oral qualifying examination, a portfolio review for admission to candidacy, and a dissertation proposal defense that culminates 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.

Master of Science (MS) 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 focused on software. This 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 and 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, which are required for the course and project options, 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 will be contingent on the credits being for suitably technical graduate-level content. To count more than 6 units from outside the CSE department, an appropriate justification for the additional increment must be provided by the adviser and student. Departmental approval will be evaluated with increasing stringency for each additional increment.
- Up to 9 units of 400-level courses can count for graduate credit.
- None of 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 grade-point average of at least 2.70.

Master of Science (MS) 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 and 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 will be contingent on the credits being for suitably technical graduate-level content. To count more than 6 units from outside the CSE department, an appropriate justification for the additional increment must be provided by the adviser and student. Departmental approval will be evaluated with increasing stringency for each additional increment.
- Up to 12 units of 400-level courses can count for graduate credit.
- None of 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 grade-point average of at least 2.70.

Master of Science (MS) in Cybersecurity Engineering

The Master of Science (MS) in Cybersecurity Engineering at Washington University will give students the skills, knowledge and expertise needed 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 required to solve complex cybersecurity problems that affect diverse enterprises worldwide.

The program includes a set of core foundational courses that focus 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 a 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	Introduction to Computer Security	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 will be evaluated with increasing stringency for each additional substitution.
- None of 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 grade-point average of at least 2.70.

Master of Engineering (MEng) 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 who for other reasons need a more flexible structure to their master's studies. The MEng offers more flexibility by allowing 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 by incorporating interdisciplinary components, when and if these are 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 tested to place out of, or completed 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 work 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 for suitably technical graduate-level content. To count more than 6 units from

outside of 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).
- CSE courses with an "N" designation do not count toward the master's degree.
- All 30 units required for the degree must be taken for a grade (i.e., not pass/fail), and the grade received in each course must be C- or better.
- As per McKelvey School of Engineering guidelines, students must maintain a grade-point average 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. 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.

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; these 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

Bruno Sinopoli (https://engineering.wustl.edu/Profiles/Pages/Bruno-Sinopoli.aspx)
Professor PhD, University of California, Berkley
Cyberphysical systems, analysis and design of networked embedded control systems, with applications to sensor actuators networks

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

Jr-Shin Li (https://engineering.wustl.edu/Profiles/Pages/Jr-Shin-Li.aspx)
Das Family Distinguished Career Development Professor
PhD, Harvard University
Mathematical control theory, optimization, quantum control, biomedical applications

Hiro 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

Neal Patwari (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=189)
Professor
PhD, University of Michigan
Intersection of statistical signal processing and wireless networking for improving wireless sensor networking and radiofrequency sensing

Heinz Schaettler (https://engineering.wustl.edu/Profiles/Pages/Heinz-Schaettler.aspx)
PhD, Rutgers University
Optimal control, nonlinear systems, mathematical models in biomedicine

Associate 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

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

Assistant Professors

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

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

Paul S. Min (https://ese.wustl.edu/faculty/Pages/Paul-Min.aspx)
PhD, University of Michigan
Routing and control of telecommunication networks, fault tolerance and reliability, software systems, network management

Robert E. Morley Jr. (https://ese.wustl.edu/faculty/Pages/Robert-Morley.aspx)
DSc, Washington University in St. Louis
Computer engineering, lower-power VLSI design, computer architecture, signal processing, microprocessors systems design

William F. Pickard (https://ese.wustl.edu/faculty/Pages/William-Pickard.aspx)
PhD, Harvard University
Biological transport, electrobiology, energy engineering

Daniel L. Rode (https://ese.wustl.edu/faculty/Pages/Daniel-Rode.aspx)
PhD, Case Western Reserve University
Optoelectronics and fiber optics, semiconductor materials, light-emitting diodes and lasers, semiconductor processing, electronics

Ervin Y. Rodin (https://ese.wustl.edu/faculty/Pages/Ervin-Rodin.aspx)
PhD, University of Texas at Austin
Optimization, differential games, artificial intelligence, mathematical modeling

Barbara A. Shrauner (https://ese.wustl.edu/faculty/Pages/Barbara-Shrauner.aspx)
PhD, Harvard University (Radcliffe)
Plasma processing, semiconductor transport, symmetries of nonlinear differential equations

Donald L. Snyder (https://ese.wustl.edu/faculty/Pages/Donald-Synder.aspx)
PhD, Massachusetts Institute of Technology
Communication theory, random process theory, signal processing, biomedical engineering, image processing, radar

Barry E. Spielman (https://ese.wustl.edu/faculty/Pages/Barry-Spielman.aspx)
PhD, Syracuse University
High-frequency/high-speed devices, radiofrequency and microwave integrated circuits, computational electromagnetics

Tzyh Jong Tarn (https://ese.wustl.edu/faculty/Pages/TJ-Tarn.aspx)
DSc, Washington University
Quantum mechanical systems, bilinear and nonlinear systems, robotics and automation, life science automation

Professors of Practice

Dedric Carter (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=149)
PhD, Nova Southeastern University
MBA, MIT Sloan School of Management

Dennis Mell (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=150)
MS, University of Missouri-Rolla
Industrial automation, robotics and mechatronics, product design and development with design-for-manufacturability emphasis, prototyping, manufacturing

Ed Richter (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=151)
MS, Washington University
Signal processing applications implemented on a variety of platforms, including ASIC, FPGA, DSP, microcontroller and desktop computers

Jason Trobaugh (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=152)
DSc, Washington University
Ultrasound imaging, diffuse optical tomography, image-guided therapy, and ultrasonic temperature imaging

Senior Lecturer

Martha Hasting (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=156)
PhD, Saint Louis University
Mathematics education

James Feher (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=155)
PhD, Missouri University of Science and Technology

Lecturers

Randall Brown (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=154)
PhD, Washington University

Randall Hoven (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=157)
MS, Johns Hopkins University

Vladimir Kurenok (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=158)
PhD, Belarus State University (Minsk, Belarus)
Probability and stochastic processes, stochastic ordinary and partial differential equations, financial mathematics

Tsitsi Madziwa-Nussinov (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=159)
PhD, University of California, Los Angeles

Jinsong Zhang (https://ese.wustl.edu/faculty/Pages/faculty.aspx?bio=160)
PhD, University of Miami
Modeling and performance analysis of wireless sensor networks, multi-source information fusion, ambiguous and incomplete information processing

Professors Emeriti

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

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; these 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 unit hours of study consistent with the residency and other applicable requirements of Washington University and McKelvey School of Engineering. The master's degrees may be pursued with a course-only option or a thesis option.

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

Please visit the following pages for more information about our programs:

- Doctoral Degrees (p. 50)
- Master of Science in Electrical Engineering (MSEE) (p. 51)
- Master of Science in Systems Science & Mathematics (MSSSM) (p. 51)
- Master of Science in Data Analytics and Statistics (MSDAS) (p. 52)
- Master of Control Engineering (MCEng) (p. 53)
- Master of Engineering in Robotics (MEngR) (p. 53)
- Certificate in Imaging Science & Engineering (IS&E) (p. 54)

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: BME T, 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. Prerequisite: 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: BME T, 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 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, Lebesque integrals, the Lp spaces, linear operators, dual space, Hilbert spaces. Projection theorem, Hahn-Banach theorem. Hyperplanes and convex sets, Gateaux and Fráchet 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: BME T, 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: BME T, TU

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: BME T, 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: BME T, 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.

Prerequisites: ESE 520 (Probability and Stochastic Processes), Math 429 (Linear Algebra) or equivalent.
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: BME T, 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: BME T, 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: BME T, 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-Poissionian photon statistics, bunching, anti-bunching, theory of photodetection, shot noise), entanglement, squeezed light, atom-photon interactions, cold atoms, abd atoms in cavities. If time permits, the following topics will be selectively covered: quantum computing, quantum cryptography, and teleportation. Prerequisites: ESE 330 and Physics 217 or Physics 421
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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: BME T, 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. Prerequisites: ESE 553 (or equivalent); ESE 520 (or equivalent); ESE 351 (or equivalent).
Credit 3 units. EN: BME T, 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: BME T, TU

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.

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: BME T, TU

E35 ESE 559 Special Topics in Systems and Control: Control of High-Dimensional Complex Systems
A rigorous introduction to recent developments in systems and controls. Focus is on the discussion of interdisciplinary applications of complex systems that motivate emerging topics in dynamics and control, and state-of-the-art methods for addressing the control and computation problems involving these large-scale systems. Topics to be covered include the control of ensemble systems, pseudospectral approximation and high-dimensional optimization, the mathematics of networks, dynamic learning and topological data analysis, and applications to biology, neuroscience, brain medicine, quantum physics, and complex networks. Both model-based and data-driven approaches are introduced. Students learn about the state-of-the-art research in the field, and ultimately apply their knowledge to conduct a final project. Prerequisite:vLinear algebra (Math 429) or equivalent, ESE 415 Optimization, ESE 551 Linear Dynamic Systems, ESE 553 Nonlinear Dynamic Systems, and ESE 520 Probability and Stochastic Processes.
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: BME T, 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 (SoC) technology is at the core of most electronic systems: smartphones, wearable devices, autonomous robots and cars, and aerospace and 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 insight into the early stage of the SoC design process by performing the tasks of developing functional specification, partition and map functions onto hardware and/or software then 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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. The first part of the 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). The second part of the 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 PHY 421 (or equivalent).
Credit 3 units. EN: BME T, 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 585A 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 the opportunity to seek the sparsest possible representation or the one with the fewest nonzeros. 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: BME T, 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: BME T, 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: BME T, 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

PhD or DSc in 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 they 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.

Below is a list of the steps needed to complete the requirements for a doctoral degree in the Department of Electrical & Systems Engineering. Each candidate for the degree must do the following:

- 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 McKelvey School of Engineering (DSc).
- Satisfy the general teaching requirement for PhD degrees offered by the Graduate School. (There is 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.

Master of Science in Electrical Engineering (MSEE)

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

Course Option

The Master of Science in Electrical Engineering 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. Under the course option, students may not take ESE 599 Master's Research. With faculty permission, they may take up to 3 units of graduate-level 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 unit hours of course instruction and 6 units hours of thesis research (ESE 599); 3 of these unit hours of thesis research may be applied toward the 15 core electrical engineering unit 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.

Degree Requirements

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

- A minimum of 15 of these unit 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 that are approved by the department. Please consult the ESE departmental website (https://ese.wustl.edu/graduate/degreeprograms/Pages/ms-electrical-engineering.aspx) for a list of allowable electives.
- 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 master's degree. Regardless of the subject or level, all transfer courses are treated as electives and do not count toward the core requirements for the degree.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken by full-time graduate students each semester. Master's 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 McKelvey School of Engineering.
- Students must obtain a cumulative grade-point average of at least 3.2 out of a possible 4.0 overall for courses applied toward the degree. Courses that apply for the degree must be taken with the credit/letter grade option.

Master of Science in Systems Science & Mathematics (MSSSM)

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

Course Option

The Master of Science in Systems Science & Mathematics (MSSSM) is an academic master's degree that requires 30 unit hours. It is designed for both full-time and part-time students interested in proceeding to the departmental full-time doctoral program and/or an industrial career. Under the course option, students may not take ESE 599 Master's Research. With faculty permission, they may take up to 3 units of graduate-level 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 unit hours of course instruction and 6 unit hours of thesis research (ESE 599); 3 of these unit hours of thesis research may be applied toward the 15 core electrical engineering unit 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.

Degree Requirements

- Required courses (15 units) for the MS degree include the following:

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 ESE or elsewhere in the university that are approved by the department. Please consult the ESE departmental website (https://ese.wustl.edu/graduate/degreeprograms/Pages/ms-systems-science-mathematics.aspx) for a list of allowable electives.
- A maximum of 6 units may be transferred from another institution and applied toward the master's degree.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken by full-time graduate students each semester. Master's 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 McKelvey School of Engineering.
- Students must obtain a cumulative grade-point average of at least 3.2 out of a possible 4.0 overall for courses applied toward the degree. Courses that apply toward the degree must be taken with the credit/letter grade option.

Master of Science in Data Analytics and Statistics (MSDAS)

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

Course Option

The Master of Science in Data Analytics and Statistics 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. Under the course option, students may not take ESE 599 Master's Research. With faculty permission, they may take up to 3 units of graduate-level 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 unit hours of course instruction and 6 unit hours of thesis research (ESE 599); 3 of these unit hours of thesis research may be applied toward the 15 core electrical engineering unit 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.

Degree Requirements

The MS in Data Analytics and Statistics (MSDAS) degree requires 30 units.

- Required courses (15 units) for the MS degree include the following:

Code	Title	Units
ESE 520	Probability and Stochastic Processes	3
or Math 495	Stochastic Processes	
ESE 524	Detection and Estimation Theory	3
Math 494	Mathematical Statistics	3
ESE 415	Optimization	3
or ESE 516	Optimization in Function Space	
or ESE 518	Optimization Methods in Control	
CSE 417T	Introduction to Machine Learning	3
or CSE 514A	Data Mining	
or CSE 530S	Database Management Systems	
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 that are approved by the department. Please consult the ESE departmental website (https://ese.wustl.edu/graduate/degreeprograms/Pages/ms-data-analytics.aspx) for a list of allowable electives.
- 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 units may be transferred from another institution and applied toward the master's degree.

- The degree program must be consistent with the residency and other applicable requirements of Washington University and the McKelvey School of Engineering.
- Students must obtain a cumulative grade-point average of at least 3.2 out of a possible 4.0 overall for courses applied toward the degree. Courses that apply toward the degree must be taken with the credit/letter grade option.

Master of Control Engineering (MCEng)

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

Course Option

The Master of Control Engineering 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. Under the course option, students may not take ESE 599 Master's Research. With faculty permission, they may take up to 3 units of graduate-level 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 unit hours of course instruction and 6 unit hours of thesis research (ESE 599); 3 of these unit hours of thesis research may be applied toward the 15 core electrical engineering unit hours required for the MSEE program. Any of the 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.

Degree Requirements

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

- Required courses (15 units) for the MCEng degree include the following:

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	3
ESE 425	Random Processes and Kalman Filtering	3
ESE 547	Robust and Adaptive Control	3
ESE 551	Linear Dynamic Systems	3
ESE 552	Linear Dynamic Systems II	3
ESE 553	Nonlinear Dynamic Systems	3

- The remaining courses in the program may be selected from senior or graduate-level courses in ESE or elsewhere in the university that are approved by the department. Please consult the ESE departmental website (https://ese.wustl.edu/graduate/degreeprograms/Pages/master-control-engineering.aspx) for a list of allowable electives.
- A maximum of 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 McKelvey School of Engineering.
- Students must obtain a cumulative grade-point average of at least a 3.2 out of a possible 4.0 overall for courses applied toward the degree. Courses that apply toward the degree must be taken with the credit/letter grade option.

Master of Engineering in Robotics (MEngR)

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

Course Option

The Master of Engineering in Robotics 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. Under the course option, students may not take ESE 599 Master's Research. With faculty permission, they may take up to 3 units of graduate-level 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 unit hours of course instruction and 6 unit hours of thesis research (ESE 599); 3 of these unit hours of thesis research may be applied toward the 15 core electrical engineering unit 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.

Degree Requirements

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.

- Required courses (the 12 units listed below as well as 9 more units from three groups) for the MEngR degree include the following:

Code	Title	Units
ESE 446	Robotics: Dynamics and Control (Spring)	3
ESE 447	Robotics Laboratory (Fall, Spring)	3
CSE 511A	Introduction to Artificial Intelligence	3
or CSE 417T	Introduction to Machine Learning	
ESE 551	Linear Dynamic Systems	3
ESE 590	Electrical & Systems Engineering Graduate Seminar (must be taken each semester)	0
Total Units		12

- At least one course must be selected from each of the following three groups for a total of 9 units:

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	Control Systems (Fall)	3
or		
MEMS 4301	Modeling, Simulation and Control (Spring)	
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 559A	Computer Vision (Spring)	3

- The remaining courses in the program may be selected from senior or graduate-level courses in ESE or elsewhere in the university that are approved by the department. Please consult the ESE departmental website (https://ese.wustl.edu/graduate/degreeprograms/Pages/meng-robotics.aspx) for a list of allowable electives.
- ESE 590 Electrical & Systems Engineering Graduate Seminar must be taken by full-time graduate students each semester. Master's students must attend at least three seminars per semester.
- A maximum of 6 units may be transferred from another institution and applied toward the master's degree.
- The degree program must be consistent with the residency and other applicable requirements of Washington University and the McKelvey School of Engineering.
- The degree must include at least 15 units of 500-level courses.
- Students must obtain a cumulative grade-point average of at least 3.2 out of a possible 4.0 overall for courses applied toward the degree. Courses that apply toward the degree must be taken with the credit/letter grade option.

Certificate in Imaging Science & Engineering (IS&E)

Washington University has been a leader in imaging science research for more than 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 McKelvey School of Engineering, with students pursuing degrees in departments across the university. The Imaging Science & Engineering (IS&E) 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. Each department has its own requirements, but all include the IS&E seminar. The program is flexible, so students are encouraged to appeal to the program director to identify individualized programs.

The IS&E certificate program is built on the strengths of 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, and molecular and neural imaging.

Imaging supports advances in earth and planetary science, enabling discovery from rovers on Mars, characterizing 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 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 completing certain requirements of the program, students are awarded a certificate indicating their successful participation in the IS&E program in addition to having completion of the certificate program posted on their official transcript. 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 IS&E 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 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 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; and 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.

Three master's programs are offered through the department: **Master of Science in Energy, Environmental & Chemical Engineering (MS), 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 making; and the opportunity to specialize in one of five pathways. The MEng/MBA is a dual degree between the McKelvey School of Engineering and the Olin Business School that 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 it 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 (SERIIUS (http://www.seriius.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)
Director of Graduate Studies
Roma B. and Raymond H. Wittcoff Distinguished University Professor
PhD, University of Connecticut
Electrochemical engineering, energy conversion

Professors

Young-Shin Jun (https://engineering.wustl.edu/Profiles/Pages/Young-Shin-Jun.aspx)
PhD, Harvard University
Aquatic processes, molecular issues in chemical kinetics, environmental chemistry, surface/physical chemistry, environmental engineering, biogeochemistry, nanotechnology

Randall Martin (https://engineering.wustl.edu/news/Pages/Martin-to-join-EECE-faculty-.aspx)
PhD, Harvard University
Characterizing atmospheric composition to inform effective policies surrounding major environmental and public health challenges ranging from air quality to climate change

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)
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 struct

Associate Professors

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 polymersure, and development of advanced aerosol instruments

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

Jason He (https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=198)
PhD, Washington University
Environmental biotechnology, bioenergy production, biological wastewater treatment, resource recovery, bio electrochemical systems, sustainable desalination technology, anaerobic digestion, forward osmosis and membrane bioreactors

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 Assistant Professor

Benjamin Kumfer (https://engineering.wustl.edu/Profiles/Pages/Ben-Kumfer.aspx)
DSc, Washington University
Advanced coal technologies, biomass combustion, aerosol processes and health effects of combustion-generated particles

Lecturers

Janie Brennan (https://engineering.wustl.edu/Profiles/Pages/Janie-Brennan.aspx)
Director of Undergraduate Studies
PhD, Purdue University
Biomaterials, chemical engineering, engineering education

Trent Silbaugh (https://engineering.wustl.edu/Profiles/Pages/Trent-Silbaugh.aspx)
PhD, University of Washington
Chemical engineering

Avni Solanki (https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=181)
PhD, University of Florida
wastewater, sustainable development, environmental engineering, and engineering education

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

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

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

Keith Tomazi
PhD, University of Missouri-Rolla
Process development engineering

Grigoriy Yablonsky
PhD, Boreskov Institute of Catalysis
Chemical reaction engineering and heterogeneous catalysis

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 degrees offered:

- PhD in Energy, Environmental & Chemical Engineering (EECE) (p. 61)
- Master of Science (MS) in Energy, Environmental & Chemical Engineering (EECE) (p. 62)

- Master of Engineering (MEng) in Energy, Environmental & Chemical Engineering (EECE) (p. 62)
- Combined Master of Engineering/Master of Business Administration (MEng/MBA) (given jointly with Olin Business School) (p. 62)

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 a unified manner to problems encountered in the areas of energy, environmental and chemical processes. A systems approach will be followed so that the general principles can be grasped, and the skills needed to develop mathematical models of seemingly different processes will be emphasized. This provides the students with general tools that they can apply later in their chosen field of research.
Credit 3 units.

E44 EECE 502 Advanced Thermodynamics in EECE
The objective of this course is to understand classical thermodynamics at a deeper level then is reached during typical undergraduate work. Emphasis will be placed on solving problems relevant to chemical engineering materials science. Prerequisite: E44 203 or equivalent.
Credit 3 units.

E44 EECE 503 Mathematical Methods in EECE
The course will introduce students to mathematical principles essential for graduate study in any engineering discipline. Applied mathematical concepts will be demonstrated by applications to various areas in energy, environmental, biomedical, chemical, mechanical, aerospace, electrical and civil engineering.
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.
Credit 3 units. EN: BME T, 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: senior or graduate-level standing.
Credit 3 units. EN: BME T, 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.
Credit 3 units. EN: BME T, TU

E44 EECE 507 Kinetics and Reaction Engineering Principles
This course is aimed at a modern multiscale treatment of kinetics of chemical and biochemical reactions and the application of these fundamentals to analyze and design reactors. Application of reaction engineering principles in areas related to energy generation, pollution prevention, chemical and biochemical processes will be 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.
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 will require the student to work under the guidance of a faculty member.

E44 EECE 509 Seminar in Energy, Environmental, and Chemical Engineering
All graduate students in EECE should attend the Departmental Seminar Series to gain exposure to various diverse fields of research. Students are also expected to participate in journal clubs and other discussion formats to discuss topical research areas. This course is required of all graduate students every semester of residency in the program.
Credit 1 unit.

E44 EECE 510 Advanced Topics in Aerosol Science & Engineering

This course will be focused on the discussion of advanced topics in aerosol science and engineering and their applications in a variety of fields, including materials science, chemical engineering, mechanical engineering, and environmental engineering. Prerequisite: EECE 504.
Credit 3 units. EN: BME T, TU

E44 EECE 512 Combustion Phenomena

This course provides an introduction to fundamental aspects of combustion phenomena, including relevant thermochemistry, fluid mechanics, and transport processes as well as the interactions among them. Emphasis is on elucidation of physico-chemical processes, problem formulation and analytic techniques. Topics covered include non-premixed and premixed flames, deflagrations and detonations, particle combustion, flame extinction, flame synthesis, pollutant formation, and methods of remediation. Contemporary topics associated with combustion are discussed throughout. Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: BME T, TU

E44 EECE 514 Atmospheric Science and Climate

This course will cover 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 will be placed on how our atmosphere and climate are altered in a world of changing energy production and land use. Prerequisites: Chemistry 112A, Physics 198, and junior or higher standing.
Credit 3 units. EN: BME T, 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 will focus on the following: (1) integral moment measurement techniques; (2) particle sizing and size distribution measuring techniques; and (3) particle composition measurement techniques. Related issues such as particle sampling and transportation, instrument calibration, and particle standards will also be covered.
Credit 3 units. EN: BME T, 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 will be 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. Prerequisites: EECE 210, Chem 112A, Chem 261.
Credit 3 units. EN: BME T, 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. Prerequisites: EECE 201; EECE 204; EECE 210 or equivalents
Credit 3 units. EN: BME T, 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; and (4) explores connections between environmental nanochemistry and environmental kinetic analysis at larger scales. This course will help 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.
Credit 3 units. EN: BME T, 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 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. No prerequisite. Both undergrad and graduate students can take this course.
Credit 3 units. EN: BME T, 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 includes relevant topics relating to biomass feedstock origin, harvest, transportation, storage, processing and pretreatment along with matters concerning thermo- and bio-chemical conversion technologies required to

produce fuels, energy, chemicals, and materials. Also, various issues with respect to biomass characterization, economics and environmental impact will be discussed. The main objective of the course is to introduce concepts central to a large-scale integrated biomass bioconversion system.
Credit 3 units. EN: BME T, 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 will cover 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 will be 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, to learn basic experimental skills, and to solve current research problems. Prerequisites: EECE 101, Bio 2960, Bio 4810.
Credit 3 units. EN: BME T, 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.
Credit 3 units. EN: BME T, 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, and copper deposition will be explored. Pre-/corequisites: EECE 501-502 (or equivalent) or permission of instructor.
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: BME T, TU

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.

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 grade-point average of at least 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 their 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 and be in 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 webpage (https://eece.wustl.edu/graduate/programs/Pages/PhD-Energy-Environmental-Chemical-Eng.aspx).

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

The MS degree is a research-focused master's program for students interested in studying environmental engineering, energy systems and chemical engineering. This degree is typically a two-year program that requires the completion of course work and a research thesis project under the supervision of a faculty member.

The program consists of 30 credits: 24 credits of course work and 6 credits of thesis research. The course work is comprised of 15 credits of core courses and 9 elective units (400 or 500 level) chosen with the approval of the adviser. Students must have a cumulative grade-point average of 2.75 or better to receive the degree. The 6 credits of thesis work are done under the guidance of a tenured or tenure-track faculty member in the department. The research results presented in the form of a written thesis must be approved by a three-person faculty committee formed with the approval of the adviser. The completion of the degree program must be consistent with the residency and other applicable requirements of Washington University and the McKelvey School of Engineering.

Doctoral students may also receive an MS in EECE "along the way" in their PhD program. They should have passed the PhD proposal defense, completed 30 units of required course work, and published or submitted at least one peer-reviewed journal manuscript from their thesis research.

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

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

This 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 and can be completed by a full-time student in 12 to 18 months.

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. Up to six elective units may be in the form of an independent study project. All courses comprising the required 30 credits must be taken for a grade (i.e., they cannot be taken pass/fail), and a minimum grade-point average 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 include the following:

- 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 webpage (https://eece.wustl.edu/graduate/programs/Pages/MEng-Energy-Environmental-Chemical-Eng.aspx).

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 that will lead to practical, effective solutions. This combined program — the Master of Engineering in Energy, Environmental & Chemical Engineering/Master of Business Administration (MEng/MBA), offered by McKelvey School of Engineering 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 and to incorporate the MEng degree requirements.

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

Please visit the Olin Combined Programs (https://olin.wustl.edu/EN-US/academic-programs/full-time-MBA/academics/joint-degrees/Pages/washu-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 in Imaging Science program at Washington University in St. Louis is **one of only two** such programs in the United States. This program offers an interdisciplinary curriculum that focuses on the technology of imaging with applications that range 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 McKelvey School of Engineering (https://engineering.wustl.edu/Pages/home.aspx) and the School of Medicine (https://medicine.wustl.edu) to provide students with the freedom and flexibility to learn from leading imaging experts and to 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

Jody O'Sullivan (https://engineering.wustl.edu/Profiles/Pages/Joseph-OSullivan.aspx)
Co-Director
Samuel C. Sachs Professor of Electrical Engineering
PhD, University of Notre Dame
Electrical & Systems Engineering

Joe Culver (https://www.mir.wustl.edu/research/research-laboratories/optical-radiology-laboratory-orl/people/joseph-culver)
Co-Director
Professor
PhD, University of Pennsylvania
Radiology; 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

Deanna Barch (https://psychiatry.wustl.edu/people/deanna-barch-phd)
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

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
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

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

Kooresh Shoghi (https://www.mir.wustl.edu/research/research-laboratories/radiological-chemistry-and-imaging-laboratory-rcil/people/biotemplate-rcil/kooresh-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-orl/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

Tiezhi Zhang (https://radonc.wustl.edu/faculty/tiezhi-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

Professor Emeritus

Martin Arthur (https://ese.wustl.edu/faculty/Pages/Martin-Arthur.aspx)
Newton R. and Sarah Louisa Glasgow Wilson Professor of Engineering
PhD, University of Pennsylvania
Electrical & Systems Engineering

Degree Requirements

PhD in Imaging Science

Requirements

To complete the PhD in Imaging Science, students must do the following:

- Maintain an average grade of B (3.0 grade-point average) 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 their administrative home department

Courses

Required Core Courses (22 units)

- BME/CSE/ESE Mathematics of Imaging Science (3 units)
- BME 593 Computational Methods for Imaging Science (3 units)
- ESE 506 Seminar in Imaging Science and Engineering (1 unit)
- 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. 67) section)

At least 12 units in elective imaging courses that span any of the following categories must be completed:

- 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. 67) 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)

Elective 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 511A Introduction to Artificial Intelligence
- CSE 512A Statistical Computing for Scientific Research
- 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 518 Optimization Methods in Control
- ESE 523 Information Theory
- ESE 524 Detection and Estimation Theory
- ESE 588 Quantitative Image Processing

Elective Courses — Imaging Sensors & Instrumentation

- BME Imaging Instrumentation
- CSE 568M Imaging Sensors

Elective 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

Elective Courses — Translational Biomedical Imaging

- BME Therapeutic Applications of Biomedical Imaging
- BME 502 Cardiovascular MRI-Physics to Clinical Application

Elective Courses — Medical Physics

- BME 507 Radiological Physics and Dosimetry
- BME 5071 Radiobiology
- BME 5072 Radiation Oncology Physics
- BME 5073 Radiation Protection and Safety

Approved Life Science Courses

- BME 503A Cell & Organ Systems
- BME 530A Molecular Cell Biology for Engineers
- BME 538 Cell Signal Transduction
- BME 5902 Cellular Neurophysiology
- Biol 404 Laboratory of 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 548 Nucleic Acids and Protein Biosynthesis
- Biol 5488 Genomics
- Biol 5571 Cellular Neurobiology (4 units)
- Biol 5651 Neural Systems
- Biol 5581 Neural Basis of Acoustic Communication
- 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 (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 the student's 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 following 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 their 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 this individual 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 it 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 the student 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. 66) 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 (e.g., chemistry, physics) frequently play a central role in developing the fundamental knowledge that is needed to design materials for a variety of engineering applications (e.g., mechanical engineering, electrical engineering, biomedical engineering). 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. The IMSE brings together a diverse group of faculty from departments in Arts & Sciences, the McKelvey School of Engineering, and the School of Medicine. The IMSE also oversees shared research and instrument facilities, develops partnerships with industry and national facilities, and facilitates outreach activities.

Current focused areas of research and advanced graduate education within the IMSE include the following:

- Biomedical, bio-derived and bio-inspired materials
- Materials for energy generation, harvesting and storage
- Materials for environmental technologies and sustainability
- Materials for sensors and imaging
- Nanomaterials and glasses
- Optoelectronic, low-dimensional, and quantum materials

Contact:	Beth Gartin
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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.

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 (https://chemistry.wustl.edu/people/william-buhro)
George E. Pake Professor in Arts & Sciences and Department Chair - Chemistry
PhD, University of California, Los Angeles

Professor Buhro's areas of interest include 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 the 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.

Guy Genin (https://engineering.wustl.edu/Profiles/Pages/Guy-Genin.aspx)
Harold and Kathleen Faught Professor of Mechanical Engineering
PhD, Harvard University

Guy Genin studies interfaces and adhesion in nature, physiology, and engineering. His current research focuses on interfaces between tissues at the attachment of tendon to bone, between cells in cardiac fibrosis, and between protein structures at the periphery of plant and animal cells.

Jianjun Guan (https://engineering.wustl.edu/Profiles/Pages/Jianjun-Guan.aspx)
Professor - Mechanical Engineering and Materials Science
PhD, Zhejiang University

Professor Guan’s research interests are in biomimetic biomaterials synthesis and scaffold fabrication; bioinspired modification of biomaterials; injectable and highly flexible hydrogels; bioimageable polymers for MRI and EPR imaging and oxygen sensing; mathematical modeling of scaffold structural and mechanical properties; stem cell differentiation; neural stem cell transplantation for brain tissue regeneration; and bone and cardiovascular tissue engineering.

Sophia E. Hayes (https://chemistry.wustl.edu/people/sophia-e-hayes)
Professor - Chemistry
PhD, University of California, Santa Barbara

Professor Hayes studies 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); CO_2 geosequestration; CO_2 capture; in situ NMR; and metal carbonate formation.

Kenneth F. Kelton (https://physics.wustl.edu/people/kenneth-f-kelton)
Arthur Holly Compton Professor of Arts & Sciences - Physics
PhD, Harvard University

Professor Kelton is involved in the 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; and hydrogen storage in quasicrystals.

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.

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).

Srikanth Singamaneni (https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx)
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.

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 nano-/micro-photonic devices from advanced materials with desired properties.

Associate Professors

Philip Skemer (https://eps.wustl.edu/people/philip-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 he 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 interests include the areas of phase routing strategies for chemical separation and phase change heat transfer processes as well as 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.

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 (https://chemistry.wustl.edu/people/alexander-barnes)
Assistant Professor - Chemistry
PhD, Massachusetts Institute of Technology

Professor Barnes studies magnetic resonance; dynamic nuclear polarization; structural biology; rational drug design; HIV eradication; Alzheimer's diease; cancer; electrical engineering; gyrotron technology; molecular biology; and 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 interests lie 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 as well as 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: (1) investigating the role of atmospheric aerosols in earth's energy balance using novel instrumentation, diagnostic techniques and numerical models; and (2) understanding aerosol formation in combustion systems toward the synthesis of high-porosity and surface-area materials for energy applications.

Julio D'Arcy (https://chemistry.wustl.edu/people/julio-m-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 the exploitation of lignocellulosic biomass — in particular, the lignin fraction of biomass — as a sustainable source for energy, chemicals and materials production.

Erik Henriksen (https://physics.wustl.edu/people/erik-henriksen)
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.

Nathaniel Huebsch (https://imse.wustl.edu/people/nathaniel-huebsch)
Assistant Professor - Biomedical Engineering

Professor Huebsch's research focus is in basic and translational stem cell mechanobiology, with specific focus on hydrogels to control cell-mediated tissue repair and 3D heart-on-a-chip models derived from human-induced pluripotent stem cells.

Matthew Lew (https://engineering.wustl.edu/Profiles/Pages/Matthew-Lew.aspx)
Assistant Professor - Electrical & Systems Engineering

Professor Lew and his students build advanced imaging systems to study biological and chemical systems at the nanoscale, leveraging innovations in applied optics, signal and image processing, design optimization, and physical chemistry. Their advanced nanoscopes (microscopes with nanometer resolution) visualize the activity of individual molecular machines inside and outside living cells. Examples of new technologies developed in the Lew Lab include (1) using tiny fluorescent molecules as sensors that can detect amyloid proteins; (2) designing new "lenses" to create imaging systems that can visualize how molecules move and tumble; and (3) new imaging software that minimizes artifacts in super-resolution images.

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 the design, development, and testing of novel energy systems and life sciences tools, from scalable micro-/nano-technologies for improved heat and mass exchangers to MEMS-based tools for the 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, Professor Mishra plans to identify and develop a quantitative measure of structure-property correlations in materials (e.g., epitaxial thin films and materials with reduced dimensionality) using a synergistic combination of scanning transmission electron microscopy and atomic-scale theory to create the rational design of materials with properties tailored for electronic, magnetic, optical and energy applications.

Ryan Ogliore (https://physics.wustl.edu/people/ryan-ogliore)
Assistant Professor - Physics
PhD, California Institute of Technology

Professor Ogliore'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.

Jai Rudra (https://engineering.wustl.edu/Profiles/Pages/Jai-Rudra.aspx)
Assistant Professor - Biomedical Engineering

Jai Rudra's lab is interested in the development of nanoscale biomaterials such as nanofibers, nanoparticles, virus-like particles, and hydrogels for engaging the immune system to induce protective antibody and cell-mediated immune responses against diseases such as tuberculosis, melanoma and flavivirus infections (i.e., West Nile and Zika). He is also investigating the development of vaccines against drugs of addiction such as cocaine. Biomaterials immunoengineering is a multidisciplinary field that lies at the intersection of materials science, chemistry, immunology and vaccinology. Professor Rudra's lab collaborates with virologists, immunologists, and clinicians not only to develop synthetic vaccination platforms but also to understand how biomaterials interact with the immune system and continue to develop novel materials and creative tools to tackle multidisciplinary problems in vaccine development and immunotherapy.

Bryce Sadtler (https://chemistry.wustl.edu/people/bryce-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 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. The goal is to discover and then understand useful interfacial phenomena. Examples of applications that we are currently interested in include transparent conducting oxides, photovoltaics, lithium-sulfur batteries, and coatings for high-temperature combustion.

Chuan Wang (https://engineering.wustl.edu/Profiles/Pages/Chuan-Wang.aspx)
Assistant Professor - Electrical and Systems Engineering

Chuan Wang's focus areas of research include (1) flexible and stretchable electronics for displaying, sensing and energy harvesting applications; (2) low-cost additive manufacturing of flexible and stretchable electronics using inkjet printing; and (3) high-performance nanoelectronics and optoelectronics using 2D semiconductors.

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 nano-structured 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 the following:

- Four IMSE Core Courses (12 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	Solid-State and Materials Chemistry	3
or Physics 472	Solid State Physics	
Total Units		12

- IMSE 500 First-Year Research Rotation (3 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 2 credits of IMSE 505 Material Science Journal Club will be permitted toward this requirement.
  - Any 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 toward 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.
- IMSE 501 IMSE Graduate Seminar every semester of full-time enrollment
- 18 to 36 credits of IMSE 600 Doctoral Research (Students must identify an IMSE faculty member willing and able to support their thesis research on a materials-related topic.)
- Students must maintain a grade-point average of at least 3.0 for all graded courses and have no more than one grade of B- or below in a core course or a Materials Science & Engineering elective.

Additional program requirements include the following:

- Complete research ethics training by the end of the third semester
- Successfully complete teaching requirements
  - Attend two or more Teaching Center Workshops
  - Complete 15 units of mentored teaching experience
- Pass the IMSE Qualifying Examination (oral and written components)
- Maintain satisfactory research progress on a topic in materials science, as determined by the thesis adviser and the 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)

- Advanced Thermodynamics in EECE (EECE 502)
- Introduction to Polymer Science and Engineering (MEMS 5608)
- IMSE Independent Study (IMSE 502) or elective
- IMSE Graduate Seminar (IMSE 501)
- Elective (optional)

Spring Semester (13 credits)

- Solid-State and Materials Chemistry (Chem 465)
- 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 IMSE Qualifying Examination (August)
  - Written document and oral presentation on research rotation
  - Oral examination on fundamentals from core courses

Years 2 and Beyond

- Electives (discuss with PhD adviser)
- IMSE Graduate Seminar (IMSE 501)
- Doctoral Research (IMSE 600)
- Teaching requirements
  - Attend two or more Teaching Center Workshops
  - Complete 15 units of mentored teaching experience
- Regular meetings (at least twice per year) with the 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 both **PhD** and **DSc** programs in **Mechanical Engineering** and **Aerospace Engineering** as well as a **DSc in Materials Science**. The department's research strengths include biomechanics and biotechnology, energy and sustainability, advanced materials and aerospace systems. The doctoral student works in conjunction with their adviser to design the program of study and the research project. The dissertation is defended at the end of the research effort. A typical time to PhD after the completion of the 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 completed using either a course option or a thesis option. For the thesis option, the student will work closely with a faculty adviser on the thesis project. A typical time for the completion of 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 and aerodynamics

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) (https://physics.wustl.edu/people/kenneth-f-kelton)
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. Sutera
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

Sharniece Holland
PhD, University of Alabama
Additive manufacturing and mathematics

Jeffery Krampf
MS, Washington University in St. Louis
Fluid mechanics, modeling, and design

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

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

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

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 more information about Mechanical Engineering & Materials Science graduate programs:

- Doctoral Degrees (p. 83)
- Master of Science in Mechanical Engineering (MSME) (p. 83)
- Master of Science in Aerospace Engineering (MSAE) (p. 84)
- Master of Science (MS) in Materials Science and Engineering (p. 85)
- Master of Engineering (MEng) in Mechanical Engineering (p. 85)

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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, TU

E37 MEMS 5404 Combustion Phenomena
Introduction to fundamental aspects of combustion phenomena, including relevant thermochemistry, fluid mechanics and transport processes, and the coupling between them. Emphasis is on elucidation of the physico-chemical processes, problem formulation and analytic techniques. Topics covered include nonpremixed and premixed flames, deflagrations and detonations, particle combustion, flame extinction, flame synthesis, pollutant formation and methods of remediation. Contemporary topics associated with combustion are discussed throughout. Prerequisites: graduate standing or permission of instructor.
Same as E44 EECE 512
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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, and two-dimensional continua. Prerequisite: ESE 501/502 or instructor's permission.
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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 bio-polymers.
Credit 3 units. EN: BME T, 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: BME T, TU

E37 MEMS 5613 Biomaterials Processing
Biomaterials with 3D structures are important for tissue regeneration. The goal of this class is to introduce various types of biomaterials and fabrication approaches to create 3D structures. The relationship between material properties, processing methods, and design will be the primary focus. The topics include degradable biomaterials for scaffold fabrication, processing of tissue engineering scaffolds, processing of tissue engineering hydrogels, processing of drug delivery systems, and scaffold surface modification.
Credit 3 units. EN: TU

E37 MEMS 5614 Polymeric Materials Synthesis and Modification
Polymer is a class of widely used material. Polymer performance is highly dependent on its chemical properties. The goal of this class is to introduce methods for the synthesis and modification of polymers with different chemical properties. The topics include free radical polymerization, reversible addition-fragmentation chain transfer polymerization, atom transfer radical polymerization, step growth polymerization, cationic polymerization, anionic polymerization, ring-opening polymerization, and bulk and surface modification of polymers.
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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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 Analysis and Design Project

The Energy Analysis and Design Project is designed to provide mechanical engineering skills in energy applications, renewable energy, and technologies related to energy which can involve heat transfer, thermodynamics, and fluid mechanics. The project topic can be chosen by the student or can be developed by both the student and faculty sponsor. The subsequent research and analysis, conducted under the guidance and direction of the faculty sponsor, results in a final project report that is approved by the faculty sponsor. The course is normally completed over one or two semesters. Recent projects have included: Energy Modeling and Efficiency Improvements: A Comparison of TRACE 700 and eQuest, Analysis of Hydroelectric Power, Optimization of Residential Solar Thermal Heating in the United States, Analysis of Ocean Thermal Energy Conversion Systems, Laboratory Plug Load Analysis and Case Study, Modeling and Optimizing Hydronic Radiant Heating and Cooling Systems using Comsol Multiphysics, CFD Analysis in HVAC Applications, Energy Analysis of Waste Disposal Methods, CFD Analysis of Containment Solutions for Data Center Cooling, Energy Recovery Ventilation, Comparative Study of Green Building Rating Systems, Grid Energy Storage, Protection of Permafrost Under the Quinghai-Tibet Railway by Heat Pipe Technology, Investing in Residential Solar Photovoltaic Systems, How Piping Layout Effects Energy Usage, and Comparison of Building Energy Savings Between China and the United States.
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.

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.

Summary of Requirements for Doctoral Students

The following is a brief summary of the requirements for students in the Mechanical Engineering & Materials Science doctoral programs:

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; a total of **72** credits is required 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) — while working with professors from the Department of Mechanical Engineering & Materials Science. For details about this program, visit the IMSE Graduate Program (http://imse.wustl.edu/graduate-program) webpage.

For more information about 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)

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 with a grade of B or better are allowed for courses taken at other graduate institutions.
- 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 from 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; 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 (e.g., T-courses, finance or entrepreneurship courses) 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)

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 with a grade of B or better are allowed for courses taken at other graduate institutions.
- 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 (e.g., T-courses, finance or entrepreneurship courses) 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

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 with a grade of B or better are allowed for courses taken at other graduate institutions.
- 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 study 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 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 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 with a grade of B or better are allowed for courses taken at other graduate institutions.
- 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 study satisfies the criteria above.

The remaining courses (electives) 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

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 ME 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 grade-point average 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. These units must be in engineering or math courses at the 400 level or above with a grade of B or better, and the courses must not be 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. 95)
- Master of Engineering Management (p. 96)
- Master of Health Care Operational Excellence (p. 97)
- Master of Information Systems Management (p. 97)
- Master of Project Management (p. 98)

Graduate Certificates

- Graduate Certificate in Construction Management (p. 93)
- Graduate Certificate in Cybersecurity Management (p. 95)
- Graduate Certificate in Engineering Management (p. 96)
- Graduate Certificate in Health Care Operational Excellence (p. 97)
- Graduate Certificate in Information Systems Management (p. 97)
- Graduate Certificate in Project Management (p. 98)

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Courses

Courses include the following:

- T54 PRJM (p. 86): Project Management
- T55 ETEM (p. 87): Engineering Management
- T64 CNST (p. 88): Construction Management
- T71 HLTHCARE (p. 89): Health Care Operations
- T81 INFO (p. 90): Information Management
- T83 CYBER (p. 92): Cybersecurity Management

Project Management

Visit online course listings to view semester offerings for T54 PRJM (https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T54).

T54 PRJM 523 Project Planning Methodologies
In this course, students will build their expertise with the critical project management methodologies needed in today's 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 used 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.

T54 PRJM 524 Hands-On With Traditional Project Management
This course presents a practical orientation for learning traditional project management techniques that produce predictable results (i.e., on time, within budget, and in accordance with stated specifications) and applying them to a project in trouble. Traditional project management is a universal

and widely used practice that includes a set of developed techniques used for planning, estimating, and controlling activities. This course also introduces the standard project life cycle: initiating, planning, executing, controlling, and closing. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 525 Project Management the Agile Way
Agile, SCRUM, Kanban, ScrumBan, SAFe: these are some of the key concepts covered in this course. Agile as a mindset, a skill set, and a tool set is critical in our fast-paced world. This course uses texts, case studies, and varying practical assignments. Students will come away with a solid understanding of the core agile concepts, frameworks, and practices that are shown to deliver great business value and that are taking the industry by storm. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 526 The Art & Science of Risk Management
This course focuses on the reasons 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 lectures, 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 these types of risk, with a focus on understanding the process of risk identification, assessment, prevention, mitigation, and recovery; governance, auditing, and control of 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 for situations in which global data is readily available, risk is pervasive, regulations are ever-increasing, and the threat of disruption from potential crises is real. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 527 Strategies of Projects, Programs & Portfolios
This course addresses the strategic alignment and prioritization of projects, programs, and portfolios, including both alignment with an organization's business objectives and alignment across the multiple projects of a portfolio. This includes the alignment and management of project resources, project schedules, and management attention. Included in this course is a team-based project simulation that offers practical exposure to negotiating and assigning project resources, which is a key success factor in project management. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 582 Developing Leadership for Professionals
This course 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. The course will combine classroom learning, actual experiences, and reality-based feedback to hone the skills that will result in an improved ability to lead.
Credit 3 units.

T54 PRJM 583 Human Performance in the Organization
In this course, students will gain insights into 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. The premise of this course is that when a leader gets better, everyone gets better. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 584 Communication Excellence for Influential Leadership
Exceptional communicators become extraordinary leaders. This course will teach students how to exceptionally communicate their messages by applying refined nuances that inspire and transform those with whom they converse. Through a proven communicative process, students will acquire the 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 their own communication capabilities, adjust to different listeners, 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. Prerequisite: graduate standing.
Credit 3 units.

T54 PRJM 585 Group Dynamics in Project Team Performance
This course examines how teams actually work by 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. Students will learn to identify the enabling conditions for team formation and the importance of context to team performance. The ideas of a standard normal person and how this relates to team behavior will be addressed. Subject areas covered include groupthink and its impact on projects; social facilitation with key stakeholders; project uncertainty and the dynamics of contribution; and project and organizational climate.
Credit 3 units.

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 504 Engineering Management & Financial Intelligence
Discover the full picture of how business works within the organization. This course walks the student through the complete business cycle and demonstrates the roles that various functions play in a business operation as well as how information is used to make business decisions (e.g. financial data, marketing data, production data, economic data). 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, and manufacturing and supply chain, with particular emphasis on accounting, finance, and the use of financial statements. 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" and blockchain 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 507 Financial Principles of the Company
This course seeks to 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, the uses of accounting data, links between accounting information and management planning, and 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.

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. According to the 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 iPhone 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, including blockchain, the "internet of things," artificial intelligence, autonomous vehicles, unmanned aerial vehicles (UAVs), 3D printing, 5G wireless networks,and 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.

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 550D 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. 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 with the construction and contracting process and with potential involvements by construction managers in the planning, design, construction, and post-construction phases. Additional topics are introduced to provide a foundation that will prepare students for future construction management coursework. 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. Prerequisite: 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 I

This capstone course allows MCM/MArch joint degree program students to apply constructability principles to their MArch degree project (A46 616 ARCH) and to 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 I is to be taken simultaneously with A46 616 ARCH Degree Project. Phase I students will develop a constructability review, analysis, and plan for their individual project. Prerequisites: admission to the MCM/MArch joint degree program; CNST 573, CNST 523A, and CNST 574C.
Credit 1 unit.

T64 CNST 581B MCM/MArch Capstone Project Phase II

This capstone course allows MCM/MArch joint degree program students to apply constructability principles to their MArch degree project (A46 ARCH 616) and to successfully demonstrate how they have applied those principles. Constructability principles include the analysis of construction methods and procedures, project cost, time, value, quality, and safety. Phase II is to be taken after completing A46 ARCH 616. Phase II students will execute the constructability plan developed in Phase I 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 502 Facilitation Skills/Change Management

This course integrates strategy and organizational due diligence with facilitation and change management strategies. By examining the relationship between employees, teams, and organizations, students will explore each level and practice assessing and facilitating team processes to maximize productivity and results for members and stakeholders. The course addresses how to get things done when teams lack leadership or authority. Supporting topics include how to build teams, how to manage meetings, how to build relationships beyond the team, and how to keep teams effective over their life span. Students will learn processes of change and the techniques of applying change to various types of organizations while using useful design frameworks for facilitation.
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.

T71 HLTHCARE 504 Six Sigma Concepts and Tools
This course is designed to teach the tools associated with the five DMAIC phases: Define, Measure, Analyze, Improve, and Control. Some of the tools considered for inclusion are the Critical-to-Quality (CTQ) matrix, Failure Modes Effectiveness Analysis (FMEA), statistical analysis, contingency tables, hypothesis testing, confidence intervals, correlation and regression, ANOVA (analysis of variation), Pareto analysis, Statistical Process Control (SPC), Measurement Systems Analysis (MSA), data collection, time studies, Root Cause Analysis (RCA), fishbone diagramming, Cost of Poor Quality (COPQ), SIPOC (Suppliers, Inputs, Process, Outputs, Customer) diagrams, detailed process mapping, cause and effect tools, and Design of Experiments (DOE).
Credit 3 units.

T71 HLTHCARE 505 Healthcare Financial Models
This course provides an overview of how healthcare financing and reimbursement systems work in the United States. The course focuses on the evolution of insurance, HMOs, and managed care. Students learn how hospitals, outpatient centers, clinicians, and other providers are reimbursed for the services. Private and public reimbursement; state rate setting; risk management; new models of reimbursement; the role of billing, coding, and accounts receivable; and managed competition are explained.
Credit 3 units.

T71 HLTHCARE 506 Innovation Science and Human Centered Design/Human Factors
This course is intended to introduce the student to the concept of "design thinking" as well as the process for innovating. It is dependent on an individual's ability to observe what people are actually doing and how they are doing it. It also requires an iterative process for understanding, synthesizing, ideating, prototyping, testing, and implementing. Emphasis will be placed on how to build stakeholder/user personas and requirements as well as how to map their emotional experiences with a process that will gain more insights than a quantitative analysis alone would provide. Healthcare needs a "human-centered" design approach to navigate the blurring of lines between product and service and between provider and patient. Designers of processes, methods, and systems now must take the needs of the entire world — including the environment — into account. Human factors will need to be applied during the iterative process to account for human factors and the parameters of users and uses.
Credit 3 units.

T71 HLTHCARE 508 Capstone Seminar
This course integrates the learning from all disciplines and subject matter presented in the Master's in Healthcare Operational Excellence program to complete a comprehensive, practical project in a healthcare-related organization. It will include a summary of the key topics covered within the program and how these apply to student's projects. The course will also focus on leading organizational change and fostering a culture of continuous improvement in healthcare and related service organizations into the future.
Credit 3 units.

T71 HLTHCARE 509 Capstone Project
The capstone project incorporates operational excellence principles, the lean management system, rapid cycle improvement methods, data analysis, change management, facilitation, project management, and healthcare cultural issues by integrating the lessons learned through the coursework to demonstrate students' mastery of operational excellence in healthcare. Students will work in multidisciplinary teams to deliver a final project that applies their cumulative coursework within the context of real industry work.
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 506 Fundamentals of Information Technology
This course is designed to provide a comprehensive survey of the information technology (IT) field. Today's enterprises rely heavily on IT to generate value, efficiency, and effectiveness. As such, organizational leaders must ensure that the enterprise transforms to keep pace in the competitive environment. Globalization, mergers and acquisitions, and the proliferation of new business and operating models require management to continuously reconsider technology infrastructures, organizational structures, process re-engineering, outsourcing, innovation, technology effectiveness, and the creation and management of data and knowledge. Given these challenges and opportunities, the IT professional has never been more crucial to organizational success. In this context, students will become familiar with core IT concepts, processes, and technology and gain an increased understanding of the crucial role of IT in the modern enterprise.
Credit 3 units.

T81 INFO 517 Operational Excellence & Service Delivery
This course examines needed management skills and processes for the efficient and effective functioning of IT infrastructure and operational environments to deliver the right set of services at the right quality and at the right costs for internal and external users and customers. Specific emphasis is placed on understanding the roles of IT operations, including system administration, network administration, help desk services, asset management, DevOps, and reporting. Students will study the application of industry best practice frameworks for the management of IT infrastructure, operations, and development. Frameworks covered include the Information Technology Infrastructure Library (ITIL) and Control Objectives for Information and Related Technology (COBIT). Through the application of continuous service improvement, students will understand the IT service life cycle and be able to assess the effectiveness of processes and services.
Credit 3 units.

T81 INFO 540 IT Architecture & Infrastructure

This course will demonstrate the importance of understanding organizational strategies and goals and then designing and deploying an information technology (IT) infrastructure that supports those strategies and goals. The course will showcase how fundamental IT building blocks are integrated in meaningful ways in order to support IT services that drive core business outcomes. Through a hands-on enterprise architecture design project, students will learn to design IT infrastructure in a rational, innovative, and cost-effective manner. We will cover a range of enterprise architecture design considerations that are commonly faced by organizations as they enhance their services, launch new products, or expand to new markets.
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 functioning 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 on both graphical processing units (GPUs) and grids. The focus is primarily on the application of deep learning to problems, with some introductory 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 with 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 563 IT Governance & Risk Management

Firms with superior information technology (IT) governance that has been designed to support the organization's strategy achieve better performance and higher profits than firms with poor (or no) governance. Just as corporate governance aims to ensure quality decisions about all corporate assets, IT governance links IT decisions with company objectives and monitors performance and accountability. This course shows how the design and implementation of an IT governance system can transform IT from an expense to a profitable investment. Essential to IT governance is risk management. In this regard, students will learn key aspects of managing risk, including risk identification, risk quantification, risk monitoring, risk control, and risk mitigation. Particular focus is placed on project risk management and understanding the process of risk identification, assessment, prevention, mitigation, and recovery as well as the roles of IT governance, auditing, and control of the confidentiality, integrity, and availability of data.
Credit 3 units.

T81 INFO 570 Leadership Seminar for Technology Professionals

This seminar is designed to develop the leadership capacity of professionals working in the information technology (IT) and cybersecurity fields. Although domain expertise plays an important role in the success of a technology professional, it is when this expertise is integrated with the ability to lead people that transforms the merely competent into multidimensional force multipliers for the organization. In this course, students will participate in an immersive seminar-based learning experience targeted toward professional and personal development on a range of essential leadership skills. Students will benefit from interaction with industry experts in the IT and cybersecurity fields and receive coaching support to achieve professional and personal goals. Each student will complete a series of self-assessments and multi-rater assessments as well as a personal leadership development plan to gain insight and build competencies critical to effective leadership. Topics include creating a shared vision, strategy development, building and sustaining a healthy culture, essentials of finance and budgeting, driving results, energizing people for performance, innovation, emotional intelligence, navigating organizational politics, managing up, negotiations, stress resilience, talent coaching and development, effective communication, and time management.
Credit 3 units.

T81 INFO 574 Foundations of Analytics

The steeply decreasing costs required to gather, store, and process data have created a strong motivation for organizations to move toward "data-driven" approaches to problem-solving. As such, data analytics continues to grow rapidly in importance across industry, government, and nonprofit organizations. This course seeks to equip students with a wide range of data analytics techniques that serve as the foundation for a broad range of applications, including descriptive, inferential, predictive, and prescriptive analytics. Students will learn the process of building a data model as well as a variety of analytics techniques and under what situations they are best employed. Through lectures and practical exercises, students will become familiar with the computational mathematics that underpin analytics; the elements of statistical modeling and machine learning; model interpretation and assessment; and structured and unstructured data analysis. Students will also undertake a project to build an analytical model using a "real-world" dataset.
Credit 3 units.

T81 INFO 575 Enterprise Data Management

Organizations have begun generating, collecting, and accumulating more data at a faster pace than ever before. The advent of "Big Data" has proven to be both opportunity and challenge for contemporary organizations who are awash in — even drowning in — data but starved for knowledge. Unfortunately, organizations have not developed comprehensive enterprise data strategy and management (EDM) practices that treat data as a strategic imperative. EDM is a comprehensive approach to defining, governing, securing, and maintaining the quality of all data involved in the business processes of an organization. EDM enables data-driven applications and decision making by establishing policies and ownership of key data types and sources. The ultimate goal is to create a strategic context for the technology underpinnings of data life cycle management and to ensure good stewardship of an organization's data. This course will cover the critical components of building an enterprise data strategy, including but not limited to data strategy, data governance, data security, data architecture, data quality, data ownership, and metadata management.
Credit 3 units.

T81 INFO 576 Analytics Applications
This course builds on the content taught in Enterprise Data Management and Foundations of Data Analytics. It focuses on the strategic, operational, tactical and practical use of data analytics to inform decisions within an organization across a range of industry and government sectors as well as within organizational functions. Students will be introduced to specific analytics techniques that are used currently by practitioners in areas of diagnostic, descriptive, predictive and prescriptive analytics. Students will learn the critical phases of analytics including data preparation, model development, evaluation, validation, selection and deployment. In so doing, students will learn to apply data analytics in order to optimize organizational processes, improve performance, and inform decision-making.
Credit 3 units.

T81 INFO 585 Capstone
This capstone course is the culmination of the Masters of Information Systems Management program. The capstone project provides the opportunity for students to employ the knowledge and skills they have gained from their course work in a rigorous and systematic manner. Projects are sponsored by external corporate, government, and non-profit organizations, and they provide the opportunity for students to deliver meaningful research and recommendations for "real-world" IT challenges and problems.
Credit 3 units.

Cybersecurity Management

Visit online course listings to view semester offerings for T83 CYBER (https://courses.wustl.edu/CourseInfo.aspx?sch=T&dept=T83).

T83 CYBER 559 Introduction to Cybersecurity
This course is a comprehensive introduction to the cybersecurity field. It covers a broad range of cybersecurity terms, definitions, historical perspectives, concepts, processes, technologies, and trends, with a focus on managing risk and the employment of cybersecurity as an organizational enabler.
Credit 3 units.

T83 CYBER 560 Cybersecurity Technical Fundamentals
This course presents a comprehensive survey of cybersecurity technology, including basic theory and concepts. Students will gain hands-on familiarity with cybersecurity technology through lab exercises, in-class studios, and scenarios. Topics covered include security considerations surrounding operating systems, the web, email, databases, wireless technology, the cloud, and the "internet of things." Also addressed are cryptography, secure software design, physical security, and human factors in cybersecurity.
Credit 3 units.

T83 CYBER 561 Oversight for Excellence: Cybersecurity Management and Governance
This course takes a comprehensive approach to the management of the organizational cybersecurity function. It also explores the principles of information technology governance. Coursework provides a deeper understanding of best practices for managing cybersecurity processes and meeting the multiple needs of enterprise management by balancing the void between business risks, technical issues, control needs, and reporting metrics. Toward this end, the course addresses a range of topics necessary for success, including the elements of and the ways to establish a governance program, cybersecurity management frameworks, developing and implementing a cybersecurity strategy, deploying cybersecurity policy and controls, ensuring standards and regulatory compliance, functional and budgetary advocacy, interfacing with the C-suite and board, and talent acquisition and development.
Credit 3 units.

T83 CYBER 562 Efficient and Effective Cybersecurity Operations
In this course, students will gain understanding of what it takes to manage the people, processes, and technology needed for effective and efficient day-to-day cybersecurity operations. Using the Cybersecurity Operations Center (CSOC) as the fundamental exemplar, students will learn the functions and processes that comprise a typical CSOC, with an underlying focus on continually optimizing operations for agility and performance. Options for structuring the CSOC will be examined along with core CSOC functions and processes, such as threat intelligence; monitoring, detection, and threat assessment; vulnerability management; incident response; prevention, including awareness training; partner and third-party coordination; analytics, metrics, and reporting; training; and CSOC technologies and instrumentation.
Credit 3 units.

T83 CYBER 563 Enterprise Network Security
This course presents a detailed and comprehensive study of the architecture and defensive approaches to protect enterprise network environments against cyber threats. Students will gain practical experience in secure network architectures and design approaches. Using a building-block approach to case studies and design exercises, the course will establish the value of applied foundational security frameworks and system models. Specific topics include defensive network design, advanced treatment of appropriate security implementation tools and techniques, boundary defense, secure wireless and mobility solutions, remote and business partner access, and third-party and vendor interactions to ensure appropriate enterprise network solutions are implemented.
Credit 3 units.

T83 CYBER 564 Access Control and Identity Management
Business advancements due to technologies such as the cloud, mobility, and the need to access information from anywhere using any device have made identity management and access control a critical component of cybersecurity. In this course, students will gain an understanding of organizational and technical identity management and access control frameworks. They will also learn central concepts such as least-privileged access, authentication, and authorization, which protect applications and systems from unapproved access. Topics covered include single sign-on, privileged account management, provisioning, role management, and directory services. Students will complete a "real-world" identity management and access control business case to identify risks and controls and to create a strategy and roadmap to address challenges and propose solutions.
Credit 3 units.

T83 CYBER 565 Cybersecurity Analytics
This course provides an introduction to the use of data analytics in support of an organization's cybersecurity function. The course is designed to increase student understanding of how data analytics can be used to manage security and be used in support of risk-based assessment and decision making. Students who complete this course successfully will be able to apply data analytics techniques and tools to help organizations discover anomalies pertaining to cyber threats; to implement, assess, and monitor basic security functions; to respond to emerging threats or prioritized requests as defined by organizational stakeholders; to depict cybersecurity risk posture within the context of compliance and regulatory requirements; and to construct a comprehensive cybersecurity analytics framework.
Credit 3 units.

T83 CYBER 566 Cybersecurity Risk Management
In this course, students will gain a deeper appreciation of the challenges faced by enterprises when addressing cybersecurity risks. The course will cover the evolution of cyber threats, including attacker methods and their targets across different industries. Students will be able to understand the differences between enterprise, operational, and cybersecurity risk management and the role that each plays (or should play) in managing risks to an organization. Students will gain technical understanding of industry-leading frameworks (i.e., COSO, ISO, NIST, and FAIR) and become conversant with their strengths and weaknesses as well as with the applicability and practicality of their implementation.
Credit 3 units.

T83 CYBER 567 The Hacker Mindset: Cyber Attack Fundamentals
This course is designed to provide an introductory understanding of how offensive security techniques practically operate. During this course, students will use hacking techniques to compromise systems, collect data, and perform other tasks that fall under the generally understood use of the term *hacker.* These techniques will be related to risk-based defensive security practices, with a view toward enhancing the student's understanding of what it takes to be a successful "defender." By the conclusion of the course, students will have a baseline technical understanding of hacking techniques; they will have executed offensive security operations, and they will have increased their technical understanding of what it takes to deal with cyber threats.
Credit 3 units.

T83 CYBER 568 Emerging Issues and Technology in Cybersecurity
Each new technology advancement brings with it promises and challenges. Will it be used for good, or will it lead to disaster? This course examines contemporary and near-future cybersecurity threats and the potential security impact of new technologies. Topics include new forms of computing and communications and their implications for cybersecurity practitioners as well as incipient threat vectors. Historical security incidents will also be used to provide context and insight into the relationship of technology and security. Throughout the course, students will be challenged to develop strategies and responses to deal with emerging technologies and threats in the ever-evolving cybersecurity domain.
Credit 3 units.

T83 CYBER 569 Incident Response and Business Continuity
This course focuses on the end-to-end processes and methods used to deal with cybersecurity incidents. Using recent examples of cyber breaches and incidents, students explore how chief information security officers react and respond to cyber breaches and incidents and learn best practices in doing so. Topics includes developing an incident response plan; organizing an incident response team; leveraging cyber intelligence and external partners to aid in response; handling public and private communications about the incident; and post-breach restoration. Particular attention will be paid to establishing a strong understanding of cybersecurity indicators and motives for espionage activities from both an external and rogue insider's perspective. Students will learn about host-based and network incident response tools and digital forensic tools, including techniques and tactics for their effective use. This section of the course includes key "hands-on" activities that are typically used during post-breach analysis and investigations, such as the forensic analysis of network storage, hard drives, and memory. Students will also become familiar with post-breach report construction and examine the proper drafting and use of such reports for submission to legal counsel, the courts, and organizational leaders.
Credit 3 units.

T83 CYBER 570 Malware Analysis and Penetration Testing
This course explores malware analysis and penetration testing methods, techniques, and tools. Students explore both static and dynamic malware analysis for hosts and networks and for a variety of executable formats, operating systems internals, and application programming interfaces. Methods to address anti-analysis techniques are addressed. As a close companion to malware analysis, the course covers the fundamentals of penetration testing, including planning, scoping and recon, scanning, target exploitation, post-exploitation, and reporting. Upon completing this course, students will be equipped with fundamental skills needed to analyze malware and to understand and apply the core concepts of penetration testing.
Credit 3 units.

T83 CYBER 587 Cloud Security
Today's organizations are more and more focused on delivering faster results and better products and services and doing this securely via an ever-evolving technological landscape. As a key component of the competitive landscape, cloud-based technologies have enabled critical capabilities, functionality, and innovations necessary to transform the way organizations survive and thrive in the competitive environment. As such, "the cloud" requires cybersecurity practitioners to think differently about managing risk, producing resilient solutions, and dealing with third-party providers. In this course, students will learn best practices for cloud security, including methods for architecting and applying security-related features in a cloud platform. Through case studies, standards, best practices, and studio exercises, students will develop the necessary skills to identify the security challenges of a cloud environment in support of the ongoing operations of the enterprise.
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 degree 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 like cost, time, risk and quality management with multidisciplinary topics such as 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.

1. Graduate Certificate (15 units, 10-15 months to complete)
2. Part-time Master's Degree (30 units, 2.5 years+ to complete)

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 McKelvey School of Engineering units and 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		
CNST 523A	Construction Cost Estimating	3
ETEM 507	Financial Principles of the Company	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 I	1
CNST 581B	MCM/MArch Capstone Project Phase II	2
Elective: Choose 3 units		
CNST 550D	Heavy Civil Construction Management	3
INFO 506	Fundamentals of Information Technology	3
INFO 575	Enterprise Data Management	3
PRJM 526	The Art & Science of Risk Management	3
PRJM 524	Hands-On With Traditional Project Management	3
CYBER 559	Introduction to Cybersecurity	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals	3
CNST 580B	Digital Construction Technology	3
ETEM 510	Understanding Emerging & Disruptive Technologies	3

Master of Construction Management

Total units required: 30

In order to earn the degree/certificate, a student must have a cumulative GPA of at least 2.70 over all courses applied toward the degree/certificate.

Code	Title	Units
Required: 18 units		
CNST 523A	Construction Cost Estimating (*)	3
ETEM 507	Financial Principles of the Company (*)	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		
Technology Concentration (Choose 12 units)		
CNST 580B	Digital Construction Technology	3
ARCH 436B	BIM in Practice	3

ARCH 462H	Information Modeling for Sustainable Design	3
ETEM 510	Understanding Emerging & Disruptive Technologies	3
INFO 506	Fundamentals of Information Technology	3
INFO 575	Enterprise Data Management	3
CYBER 559	Introduction to Cybersecurity	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals	3
Project Management Concentration (Choose 12 units)		
CNST 550D	Heavy Civil Construction Management	3
PRJM 526	The Art & Science of Risk Management	3
PRJM 524	Hands-On With Traditional Project Management	3
ARCH 447A	Structures I	3
ARCH 448A	Structures II	3
Leadership Concentration (Choose 12 units)		
PRJM 582	Developing Leadership for Professionals	3
PRJM 585	Group Dynamics in Project Team Performance	3
PRJM 584	Communication Excellence for Influential Leadership	3
PRJM 583	Human Performance in the Organization	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 30-unit part-time program designed for working professionals. This program was developed with one critical goal: to educate professionals about how to manage the people and resources required to perform these tasks and to lead the cybersecurity functions of various organizations.

The curriculum provides students with the knowledge needed to protect from, defend against, respond to and recover after 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 (30 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: 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: Choose 21 units		
CYBER 560	Cybersecurity Technical Fundamentals (*)	3
CYBER 561	Oversight for Excellence: Cybersecurity Management and Governance (*)	3
CYBER 562	Efficient and Effective Cybersecurity Operations (*)	3
CYBER 566	Cybersecurity Risk Management (*)	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals (*)	3
INFO 570	Leadership Seminar for Technology Professionals	3
CYBER 587	Cloud Security	3
Cybersecurity Emphasis: Choose 9 units		
CYBER 563	Enterprise Network Security	3
CYBER 564	Access Control and Identity Management	3
CYBER 565	Cybersecurity Analytics	3
CYBER 568	Emerging Issues and Technology in Cybersecurity	3
CYBER 569	Incident Response and Business Continuity	3

CYBER 570	Malware Analysis and Penetration Testing	3
Cybersecurity Design & Engineering Emphasis Elective Courses: Choose 9 units		
CSE 571S	Network Security	3
CSE 523S	Systems Security	3
CSE 422S	Operating Systems Organization	3
CSE 469S	Security of the Internet of Things and Embedded System Security	3
CSE 433S	Introduction to Computer Security	3
Bridge Course: 3 units**		
CYBER 559	Introduction to Cybersecurity	3

(*) Courses required to earn a 15-unit Graduate Certificate in Cybersecurity Management.

(**) The bridge course is offered for students with limited to no cybersecurity background. The successfully completed course will count toward the 9 required elective units.

Engineering Management

The newly revised Master of Engineering Management program bridges the gap between technology and business by providing students with the technical expertise and leadership skills needed to advance their careers. The 30-unit Master of Engineering Management is available for full-time or part-time students.

This program brings together Washington University 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		
ETEM 504	Engineering Management & Financial Intelligence (*)	3
ETEM 505	Decision-Making & Optimization (*)	3
ETEM 506	Technology Strategy & Marketing (*)	3
ETEM 507	Financial Principles of the Company (*)	3
ETEM 510	Understanding Emerging & Disruptive Technologies (*)	3
PRJM 523	Project Planning Methodologies	3
PRJM 583	Human Performance in the Organization	3
Data Analytics Emphasis: Choose 9 units		
INFO 506	Fundamentals of Information Technology	3
INFO 574	Foundations of Analytics	3
INFO 575	Enterprise Data Management	3
INFO 576	Analytics Applications	3
Technology Emphasis: Choose 9 units		
CYBER 559	Introduction to Cybersecurity	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals	3
CSE 501N	Introduction to Computer Science	3
CSE 502N	Data Structures and Algorithms	3
Organizational Development & Management Emphasis: Choose 9 units		
PRJM 582	Developing Leadership for Professionals	3
PRJM 585	Group Dynamics in Project Team Performance	3
PRJM 584	Communication Excellence for Influential Leadership	3
Project Management & Operational Excellence Emphasis: Choose 9 units		
PRJM 524	Hands-On With Traditional Project Management	3
PRJM 525	Project Management the Agile Way	3
PRJM 526	The Art & Science of Risk Management	3

PRJM 527	Strategies of Projects, Programs & Portfolios	3
HLTHCARE 502	Facilitation Skills/Change Management	3
HLTHCARE 503	Lean Healthcare Concepts, Tools and Lean Management Systems	3
HLTHCARE 504	Six Sigma Concepts and Tools	3
CNST 572	Legal Aspects of Construction	3
CNST 573	Fundamentals in Construction Management	3
CNST 523A	Construction Cost Estimating	3

(*) Courses required to earn a 15-unit Graduate Certificate in Engineering Management.

Health Care Operational Excellence

The quality and efficiency of health care systems are of increasing importance at every level and in every 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. The 15-unit Graduate Certificate allows students to take the courses that make up the core curriculum of the degree program and to then apply those credits toward the degree at a future date.

This program is designed to create thought leaders in continuous improvement, employee engagement, value-stream mapping and operational excellence. Because it is focused on continuous improvement methodologies, the curriculum offered by this degree program prepares leaders in service, health care and other operational environments to utilize a tool set that allows them to eliminate waste, innovate, and improve patient and employee experiences in St. Louis and around the globe.

1. Graduate Certificate (15 units, 10-15 months to complete)
2. Part-time Master's Degree (30 units, three years to complete)

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/Leroy-Love.aspx)
Director of Graduate Studies in Health Care Operational Excellence
MS, Missouri University of Science & Technology
BS, University of Missouri-Columbia

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: 30 units

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
HLTHCARE 504	Six Sigma Concepts and Tools (*)	3
PRJM 523	Project Planning Methodologies (*)	3
HLTHCARE 505	Healthcare Financial Models	3
HLTHCARE 506	Innovation Science and Human Centered Design/Human Factors	3
HLTHCARE 508	Capstone Seminar	3
HLTHCARE 509	Capstone Project	3
Electives (Choose 3 units)		
PRJM 526	The Art & Science of Risk Management	3

Electives: 3 units

(*) Courses required to earn a 15-unit Graduate Certificate in Health Care Operational Excellence.

Information Systems Management

Building on more than 30 years of innovative graduate education and professional development programs in information technology, the McKelvey School of Engineering at Washington University in St. Louis now offers a 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.

This integrated program is a key component of 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: 18 units		
INFO 517	Operational Excellence & Service Delivery (*)	3
INFO 540	IT Architecture & Infrastructure (*)	3
INFO 563	IT Governance & Risk Management (*)	3
INFO 575	Enterprise Data Management (*)	3
CYBER 559	Introduction to Cybersecurity (*)	3
INFO 585	Capstone	3
Cybersecurity Emphasis: Choose 12 units		
CYBER 560	Cybersecurity Technical Fundamentals	3
CYBER 561	Oversight for Excellence: Cybersecurity Management and Governance	3
CYBER 562	Efficient and Effective Cybersecurity Operations	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals	3
Management Emphasis: Choose 12 units		
PRJM 582	Developing Leadership for Professionals	3
PRJM 583	Human Performance in the Organization	3
PRJM 584	Communication Excellence for Influential Leadership	3
ETEM 507	Financial Principles of the Company	3
Applied Data Analytics Emphasis: Choose 12 units		
INFO 558	Applications of Deep Neural Networks	3
INFO 574	Foundations of Analytics	3
INFO 576	Analytics Applications	3
Mathematical Data Analytics Emphasis: Choose 12 units		
Math 494	Mathematical Statistics	3
ESE 415	Optimization	3
CSE 511A	Introduction to Artificial Intelligence	3
CSE 514A	Data Mining	3
CSE 517A	Machine Learning	3
AI & Machine Learning Emphasis: Choose 12 units		
CSE 511A	Introduction to Artificial Intelligence	3
CSE 514A	Data Mining	3
CSE 517A	Machine Learning	3
CSE 519T	Advanced Machine Learning	3
Bridge Course: 3 units		
INFO 506	Fundamentals of Information Technology	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 of this program was designed to teach the execution of mission-critical projects and to help students conquer the three project environments of people, processes and strategies. The 30-unit Master of Project Management is offered in a part-time evening format for working professionals. 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: 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: 21 units		
PRJM 523	Project Planning Methodologies (*)	3
PRJM 524	Hands-On With Traditional Project Management (*)	3
PRJM 525	Project Management the Agile Way (*)	3
PRJM 526	The Art & Science of Risk Management (*)	3
PRJM 527	Strategies of Projects, Programs & Portfolios (*)	3
PRJM 583	Human Performance in the Organization	3
PRJM 584	Communication Excellence for Influential Leadership	3
Data Analytics Emphasis: choose 9 units		
INFO 506	Fundamentals of Information Technology	3
INFO 574	Foundations of Analytics	3
INFO 575	Enterprise Data Management	3
INFO 576	Analytics Applications	3
Technology Emphasis: choose 9 units		
ETEM 510	Understanding Emerging & Disruptive Technologies	3
CYBER 559	Introduction to Cybersecurity	3
CYBER 567	The Hacker Mindset: Cyber Attack Fundamentals	3
CSE 501N	Introduction to Computer Science	3
CSE 502N	Data Structures and Algorithms	3
Organizational Development & Management Emphasis: choose 9 units		
PRJM 582	Developing Leadership for Professionals	3
PRJM 585	Group Dynamics in Project Team Performance	3
ETEM 504	Engineering Management & Financial Intelligence	3
ETEM 506	Technology Strategy & Marketing	3
Operational Excellence Emphasis: choose 9 units		
HLTHCARE 502	Facilitation Skills/Change Management	3
HLTHCARE 503	Lean Healthcare Concepts, Tools and Lean Management Systems	3
HLTHCARE 504	Six Sigma Concepts and Tools	3
CNST 572	Legal Aspects of Construction	3
CNST 573	Fundamentals in Construction Management	3
CNST 523A	Construction Cost Estimating	3

(*) Courses required to earn a 15-unit Graduate Certificate in Project Management.

Degrees Offered

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
314-935-6070

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.

McKelvey School of Engineering 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 McKelvey School of Engineering. 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 the Biomedical Innovation program in Biomedical Engineering. Official test scores are required at the time of application.

Admission 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, and they 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 McKelvey School of Engineering. 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 on a pass/fail basis cannot be counted toward the degree. Students should consult their advisers regarding these options.

International students who are required to submit a TOEFL or IELTS score and who have not studied previously for a minimum of three years in a U.S. school will be required to take an Engineering Communication Tools course during their first semester. This course does not count toward degree requirements and does not require any additional tuition; it is graded on a pass/fail basis, so it is not factored into the grade-point average.

Course Load

The normal load for full-time graduate students is 9 to 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 for 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 email the Office of the University Registrar (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 9 or more units or an active part-time status if enrolled in fewer than 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 during their final semester. In order to have part-time status during their final semester, international master's students must complete a Reduced Course Load form, which is 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 during their final semester and 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 the Nonresident/Inactive Status should register using the Exx 886 course number. A master's student should register for this 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 ensure 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 OISS. 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 Graduate Student Services at 314-935-5830, 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 their previous work 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 and A+ = 4, B = 3 and C = 2. A plus adds 0.3 to the value of a grade (with the exception of an A+ grade), whereas a minus subtracts 0.3 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.

*Physical Education (L28) and University College courses will not count in GPA calculations or toward earned units in Engineering master's degrees.

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 the minimal standards of satisfactory academic progress for Doctor of Science and Master's students. Degree programs may set stricter standards, but they may not relax those listed below. Acceptability of grades below B- for the fulfillment of degree requirements is determined by individual departments.

Doctor of Science (DSc) students must maintain a cumulative GPA of at least 3.00.

- Academic probation occurs if a semester or cumulative GPA 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 GPA less than 2.00, or
  - Has been on probation for two semesters and has not attained a 3.00 cumulative GPA.

Master's students must maintain a cumulative GPA of at least 2.70.

- Academic probation occurs if a semester or cumulative GPA 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 GPA less than 2.00, or
  - Has been on probation for two semesters and has not attained a 2.70 cumulative GPA.

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 must meet with the Assistant Director of Graduate Student Services. This meeting will serve as an opportunity for the student to identify areas for improvement and to create a strategy for success for the duration of their degree program.

Academic **suspension** represents being dismissed from the school. Students placed on academic suspension are not eligible to enroll or to continue their degree programs.

Students who are suspended may petition the registrar in the McKelvey School of Engineering 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, for at least one year), that they have been employed in a full-time position (generally, for at least 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 may go toward the Doctor of Science degree. Transfer credit must be recommended by the adviser, department or program chairman and 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 those courses have the 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. 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 (e.g., 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 Disability Resources 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 McKelvey School of Engineering 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 (http://shs.wustl.edu) submitted to the appropriate dean in the McKelvey School of Engineering 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 McKelvey School of Engineering are expected to conform to high standards of conduct. This statement on student academic integrity is intended to provide guidelines on academic behaviors that are not acceptable.

It is dishonest and a violation of academic integrity if any of the following occurs:

1. A student turns in work that is represented as their own when in fact they have significant outside help. When a student turns in work with their name on it, they are in effect stating that the work is theirs and theirs alone.
2. A student uses the results of another person's work (e.g., exam, homework, computer code, lab report) and represents 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 when 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 that 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; and cite the source of such material by listing the author, the title of the work, the publication in which it appeared, and the 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 & 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 2019-20 tuition and fees (https://engineering.wustl.edu/prospective-students/graduate-admissions/Pages/tuition-financial-assistance.aspx) for graduate students in the McKelvey School of Engineering 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** graduate 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 four to six 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 (i.e., 3 units in the summer and 4.5 units in the fall and spring) and who 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 Janna Schmitt at by phone at 314-935-8460 or by email at j.schmitt@wustl.edu.

Loans

The federal government provides a number of student loan programs, and there are rules and requirements for each program. These programs are subject to change by the government agencies that oversee them, and they require that detailed financial information be provided by the student. For more information about 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 of 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. 106).
- The Skandalaris Center (p. 107) 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. 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 IE program may have specific limitations or requirements for participation; details are available in those offices.

The following provisions apply to all course work taken by Washington University students attending SLU or UMSL through the IE program:

- Such courses can be used for 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 their grade-point average, 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 and 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 IE program 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 the department chair at SLU or UMSL, preferably in person.
4. The student also must obtain the 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 I97 (SLU) and I98 (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, staff, and, on occasion, the community. We call this the **SC Network.**

Our Initiatives

Our initiatives are divided into three parts:

1. **Get Connected** (p. 107)
2. **Get Trained** (p. 107)
3. **Get Funded** (p. 107)

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 webpage (https://skandalaris.wustl.edu/get-connected/student-orgs).

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. **Summer Entrepreneurial Internship Program** (http://skandalaris.wustl.edu/training/internship)
   This 10-week summer program offers undergraduate students in any school the opportunity to experience entrepreneurship in a real-world setting through a paid internship at an early stage startup. Each week on Wednesdays, students participate in unique activities, including site visits to startups or co-working spaces, panel discussions, and visits to St. Louis neighborhoods. Applications generally run from early January to early February each year.
2. **Student Entrepreneurial Program (StEP)** (http://skandalaris.wustl.edu/training/step)
   StEP provides a unique opportunity for students to own and operate a business on or off campus. Student owners can supplement the valuable business and entrepreneurial skills they learn in the classroom while gaining real-world experience as they manage and lead their own businesses.
3. **IdeaBounce®** (https://skandalaris.wustl.edu/training/ideabounce)
   IdeaBounce® is both an online platform and an event for sharing venture ideas and making connections. This is an opportunity for participants to pitch their idea (no matter how "fresh"), get feedback on it, and make connections. In-person events happen around twice per semester.
4. **The 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 it 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 the following business plan competitions for Washington University students:

The Suren G. Dutia and Jas K. Grewal Global Impact Award (GIA) (http://skandalaris.wustl.edu/funding/global-impact-award)

The 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

Skandalaris Venture Competition (SVC) (https://skandalaris.wustl.edu/funding/skandalaris-venture-competition)

The SVC provides expert mentorship to new ventures and startups to ready them for commercializing their idea, launching, and pitching to investors.

- **Who Can Apply:** Current Washington University students
- **Award:** Up to $15K

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!

Phone:	314-935-9134
Email:	sc@wustl.edu
Website:	http://skandalaris.wustl.edu

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