MECHANICAL ENGINEERING

Courses offered by the Department of Mechanical Engineering are listed under the subject code ME on the *Stanford Bulletin's* ExploreCourses web site.

The programs in the Department of Mechanical Engineering (ME) emphasize a mix of applied mechanics, biomechanical engineering, computer simulations, design, and energy science and technology. Since mechanical engineering is a broad discipline, the undergraduate program can be a springboard for graduate study in business, law, medicine, political science, and other professions where understanding technology is important. Both undergraduate and graduate programs provide technical background for work in biomechanical engineering, environmental pollution control, ocean engineering, transportation, and other multidisciplinary problems that concern society. In all programs, emphasis is placed on developing systematic procedures for analysis, creating innovative solutions to complex problems, communication of work and ideas, practical and human-centered and aesthetic aspects in design, and responsible use of technology.

Mission of the Undergraduate Program in Mechanical Engineering

The mission of the undergraduate program in Mechanical Engineering is to provide students with a balance of intellectual and practical experiences that enable them to address a variety of societal needs. The curriculum encompasses elements from a wide array of disciplines built around the themes of biomechanical engineering, computational engineering, design, energy, materials, and multiscale engineering. Course work may include mechatronics, computational simulation, solid and fluid dynamics, microelectromechanical systems, biomechanical engineering, energy science and technology, propulsion, sensing and control, nano- and micro-mechanics, and design. The program prepares students for entry-level work as mechanical engineers and for graduate studies in either an engineering discipline or another field where a broad engineering background is useful.

Learning Objectives (Undergraduate)

These outcomes are operationalized through learning objectives, which students are expected to demonstrate:

1. Graduates of the program will have the scientific and technical background for successful careers in diverse organizations.
2. Graduates of the program will be leaders, and effective communicators, both in the profession and in the community.
3. Graduates of the program will be motivated and equipped to successfully pursue postgraduate study whether in engineering, or in other fields.
4. Graduates of the program will have a professional and ethical approach to their careers with a strong awareness of the social contexts in which they work.

Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through course work providing depth in one area of specialization and breadth in complementary areas. Areas of specialization range from automatic controls, energy systems, fluid mechanics, heat transfer, and solid mechanics to biomechanical engineering, MEMS, and design.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Mechanical Engineering and related fields.

Graduate Programs in Mechanical Engineering

Admission and Financial Assistance

Mechanical engineering is a varied profession, ranging from primarily aesthetic aspects of design to highly technical scientific research. Disciplinary areas of interest to mechanical engineers include biomechanics, energy conversion, fluid mechanics, materials, nuclear reactor engineering, propulsion, rigid and elastic body mechanics, systems engineering, scientific computing, thermodynamics, robotics, and controls, to name a few. Our graduate programs provide advanced depth and breadth in the field.

Graduate degree programs and admission

- Master of Science (M.S.) in Mechanical Engineering
- Master of Science (M.S.) in Engineering — Design Impact
- Doctor of Philosophy (Ph.D.) in Mechanical Engineering

To be eligible for admission to graduate study to the department, a student must have a B.S. degree in engineering, physics, or a comparable science program. M.S. and Ph.D. applications must be received by the first Tuesday in December, and admitted students must matriculate in the following Autumn. In rare circumstances, with the support of an ME faculty member who is a potential Ph.D. adviser, Ph.D. applications from students who have completed or are currently in an M.S. program are reviewed for Winter or Spring Quarter start. In addition, M.S. applicants eligible for the Honors Cooperative Program (on-campus courses required for Mechanical Engineering) can apply in Autumn, Winter, or Spring quarters.

Additional degree programs available to currently enrolled students

- Master of Science (M.S.) in Engineering — Biomechanical Engineering
- Master of Science (M.S.) in Engineering — Individually Designed Major
- Engineer in Mechanical Engineering

For additional information about these programs, see the Mechanical Engineering Department Graduate Handbook.

Financial Assistance

The department annually awards, on a competitive basis, a limited number of fellowships, teaching assistantships, and research assistantships to incoming graduate students. For M.S. students, limited financial aid in the form of fellowships and short-term research assistantships are provided at the time of admission, and course assistantships can sometimes be arranged with individual course instructors after admission. All Ph.D. students receive financial support for the duration of their program, given satisfactory degree progress.

Post-Master's Degree Programs

The department offers two post-master's degrees: Engineer and Doctor of Philosophy. Post-master's research generally requires some evidence that a student has research potential before a faculty member agrees to supervision and a research assistantship appointment. It is most efficient to carry out preliminary research during the M.S. degree program, if interested in a post-master's degree.

Departmental Groups

The department has five groups: Biomechanical Engineering; Design; Flow Physics and Computation; Mechanics and Computation; and Thermosciences. Each maintains its own labs, shops, and offices.

The Biomechanical Engineering (BME) Group has teaching and research activities which focus primarily on musculoskeletal biomechanics, neuromuscular biomechanics, cardiovascular biomechanics, and rehabilitation engineering. Research in other areas including hearing, ocean, plant, and vision biomechanics exists in collaboration with associated faculty in biology, engineering, and medicine. The group has strong research interactions with the Mechanics and Computation and the Design groups, and the departments of Neurology, Radiology, and Surgery in the School of Medicine.

The Design Group is devoted to the imaginative application of science, technology, and art to the conception, visualization, creation, analysis and realization of useful devices, products, and objects. Courses and research focus on topics such as bio-inspired design, kinematics, haptics, applied finite elements, micro-electricalmechanical systems (MEMS), medical devices, fatigue and fracture mechanics, dynamics and simulation, rehabilitation, optimization, high-speed devices, product design, vehicle dynamics, experimental mechanics, robotics, creativity, idea visualization, computer-aided design, manufacturing technology, design analysis, and engineering education.

The Flow Physics and Computational Engineering Group (FPCE) The Flow Physics and Computational Engineering Group (FPCE) blends research on flow physics and modeling with algorithm development, scientific computing, and numerical database construction. FPCE is contributing new theories, models and computational tools for accurate engineering design analysis and control of complex flows (including multi phase flows, micro-fluidics, chemical reactions, acoustics, plasmas, interactions with electromagnetic waves and other phenomena) in aerodynamics, propulsion and power systems, materials processing, electronics cooling, environmental engineering, and other areas. A significant emphasis of research is on modeling and analysis of physical phenomena in engineering systems.

The Mechanics and Computational Group covers biomechanics, continuum mechanics, dynamics, experimental and computational mechanics, finite element analysis, fluid dynamics, fracture mechanics, micromechanics, nanotechnology, and simulation based design. Qualified students can work as research project assistants, engaging in thesis research in association with the faculty director and fellow students. Projects include analysis, synthesis, and control of systems; biomechanics; flow dynamics of liquids and gases; fracture and micro-mechanics, vibrations, and nonlinear dynamics; and original theoretical, computational, and experimental investigations in the strength and deformability of elastic and inelastic elements of machines and structures.

The Thermosciences Group conducts experimental and analytical research on both fundamental and applied topics in the general area of thermal and fluid systems. Research strengths include high Reynolds number flows, microfluidics, combustion and reacting flows, multiphase flow and combustion, plasma sciences, gas physics and chemistry, laser diagnostics, microscale heat transfer, convective heat transfer, and energy systems. Research motivation comes from applications including air-breathing and space propulsion, bioanalytical systems, pollution control, electronics fabrication and cooling, stationary and mobile energy systems, biomedical systems, and materials processing. Emphasis is on fundamental experiments leading towards advances in modeling, optimization, and control of complex systems.

Facilities

The department groups maintain modern laboratories that support undergraduate and graduate instruction and graduate research work. A partial listing can be found below. More information is available at the department's Labs and Centers (http://me.stanford.edu/research/labs-and-centers/) website.

The d'Arbeloff Undergraduate Research and Teaching Lab supports undergraduate research and teaching in the Mechanical Engineering Department. In this unique facility, the department holds undergraduate project-based classes, and offers its students the opportunity to build and collaborate.

The Structures and Composites Laboratory, a joint activity with the Department of Aeronautics and Astronautics, studies structures made of fiber-reinforced composite materials. Equipment for fabricating structural elements includes autoclave, filament winder, and presses. X-ray, ultrasound, and an electron microscope are available for nondestructive testing. The lab also has environmental chambers, a high speed impactor, and mechanical testers. Lab projects include designing composite structures, developing novel manufacturing processes, and evaluating environmental effects on composites.

Experimental facilities are available through the interdepartmental Structures and Solid Mechanics Research Laboratory, which includes an electrohydraulic materials testing system, a vehicle crash simulator, and a shake table for earthquake engineering and related studies, together with highly sophisticated auxiliary instrumentation. Facilities to study the micromechanics of fracture areas are available in the Micromechanics/Fracture Laboratory, and include a computer-controlled materials testing system, a long distance microscope, an atomic force microscope, and other instrumentation. Additional facilities for evaluation of materials are available through the Center for Materials Research, Center for Integrated Circuits, and the Ginzton Laboratory. Laboratories for biological experimentation are accessible through the School of Medicine. Individual accommodation is available for the work of each research student.

Major experimental and computational laboratories engaged in bioengineering work are located in the Biomechanical Engineering Group. Other Biomechanical Engineering Group activities and resources are associated with the Rehabilitation Research and Development Center of the Veterans Administration Palo Alto Health Care System. This major national research center has computational and prototyping facilities. In addition, the Rehabilitation Research and Development Center houses the Electrophysiology Laboratory, Experimental Mechanics Laboratory, Human Motor Control Laboratory, Rehabilitation Device Design Laboratory, and Skeletal Biomechanics Laboratory. These facilities support graduate course work as well as Ph.D. student research activities.

Computational and experimental work is also conducted in various facilities throughout the School of Engineering and the School of Medicine, particularly the Advanced Biomaterials Testing Laboratory of the Department of Materials Science and Engineering, the Orthopaedic Research Laboratory in the Department of Functional Restoration, and the Vascular Research Laboratory in the Department of Surgery. In collaboration with the School of Medicine, facilities throughout the Stanford Medical Center and the Veterans Administration Palo Alto Health Care System conduct biological and clinical work.

The Design Group has facilities for lab work in experimental stress analysis. Design Group students also have access to the Stanford NanoFabrication Facility (SNF) and characterization facilities at the Stanford Nano Shared Facilities (SNSF).

The Automotive Innovation Facility houses the Volkswagen Automotive Innovation Lab (VAIL) which provides a state-of-the-art vehicle research facility and community space where interdisciplinary teams work on projects that move vehicle technology forward by focusing on human-centered mobiling solutions. High-profile Stanford projects accommodated in the building include research on drive-by-wire and drive assistance systems, and the interaction of drivers with vehicles (via the full–scale driving simulator).

The Design Group also maintains the Product Realization Laboratory (PRL), a multi-site teaching facility offering students integrated experiences in market definition, product design, and prototype manufacturing. The PRL provides coaching, design manufacturing tools, and networking opportunities to students interested in product development. The PRL's Room 36 offerings include laser cutters, 3D printers, sewing machines, and equipment for work with electronics and hotwire foam cutting, The ME 310 Design Project Laboratory has facilities for CAD, assembly, and testing of original designs by master's students in the engineering design program. The Smart Product Design Laboratory supports microprocessor application projects.

The Center for Design Research (CDR) is a unique doctoral-level research community that studies the dynamics of science, engineering, management, and design teams in academic and worldly settings internationally. This closely knit group studies human/machine interactions from both technology and human performance points of view: why did the robot (autonomous car; surgical robot; instructor) do that? Why is the team doing that? Smart technical systems are never smart enough at the interface with humans and the human environment. Stanford courses, especially ME 310, often serve as laboratories for the researchers. The CDR collaborates closely with other disciplines and laboratories, especially Computer Science (AI, big data), the behavioral sciences (VR, AR), and the School of Medicine (haptics, neurosciences, fMRI, fNIRS).

The Nanoscale Prototyping Laboratory addresses fundamental issues on energy conversion and storage at the nanoscale. It employs a wide range of nano-fabrication technologies to build prototype fuel cells and capacitors with induced topological electronic states. It tests these concepts and novel material structures with the help of atomic layer deposition, scanning tunneling microscopy, impedance spectroscopy and other technologies. In addition, it uses atomic scale modeling to gain insights into the nature of charge separation and recombination processes.

The Design Group also maintains The Loft, in which students in the Design Impact Program develop graduate thesis projects.

The Flow Physics and Computation Group has a 32 processor Origin 2000, 48-node and 85-node Linux cluster with high performance interconnection and an array of powerful workstations for graphics and data analysis. Several software packages are available, including all the major commercial CFD codes. FPC is strongly allied with the Center for Turbulence Research (CTR), a research consortium between Stanford and NASA, and the Center for Integrated Turbulence Simulations (CITS), which is supported by the Department of Energy (DOE) under its Accelerated Strategic Computing Initiative (ASCI). The Center for Turbulence Research has direct access to major national computing facilities located at the nearby NASA-Ames Research Center, including massively parallel super computers. The Center for Integrated Turbulence Simulations has access to DOE's vast supercomputer resources. The intellectual atmosphere of the Flow Physics and Computation Group is greatly enhanced by the interactions among CTR's and CITS's postdoctoral researchers and distinguished visiting scientists.

The Mechanics and Computation Group has a Computational Mechanics Laboratory that provides an integrated computational environment for research and research-related education in computational mechanics and scientific computing. The laboratory houses Silicon Graphics, Sun, and HP workstations and servers, including an 8-processor SGI Origin2000 and a 16-processor networked cluster of Intel-architecture workstations for parallel and distributed computing solutions of computationally intensive problems. Software is available on the laboratory machines, including commercial packages for engineering analysis, parametric geometry and meshing, and computational mathematics. The laboratory supports basic research in computational mechanics as well as the development of related applications such as simulation-based design technology.

The Thermosciences Group has four major laboratory facilities. The Heat Transfer and Turbulence Mechanics Laboratory concentrates on fundamental research aimed at understanding and improved prediction of turbulent flows and high performance energy conversion systems. The laboratory includes two general-purpose wind tunnels, a pressurized high Reynolds number tunnel, two supersonic cascade flow facilities, three specialized boundary layer wind tunnels, and several other flow facilities. Extensive diagnostic equipment is available, including multiple particle-image velocimetry and laser-Doppler anemometry systems.

The High Temperature Gas Dynamics Laboratory includes research on sensors, plasma sciences, cool and biomass combustion and gas pollutant formation, and reactive and non-reactive gas dynamics. Research facilities include diagnostic devices for combustion gases, a spray combustion facility, laboratory combustors including a coal combustion facility and supersonic combustion facilities, several advanced laser systems, a variety of plasma facilities, a pulsed detonation facility, and four shock tubes and tunnels. The Thermosciences Group and the Design Group share the Microscale Thermal and Mechanical Characterization laboratory (MTMC). MTMC is dedicated to the measurement of thermal and mechanical properties in thin-film systems, including microfabricated sensors and actuators and integrated circuits, and features a nanosecond scanning laser thermometry facility, a laser interferometer, a near-field optical microscope, and an atomic force microscope. The activities at MTMC are closely linked to those at the Heat Transfer Teaching Laboratory (HTTL), where undergraduate and master's students use high-resolution probe stations to study thermal phenomena in integrated circuits and thermally-actuated microvalves. HTTL also provides macroscopic experiments in convection and radiative exchange.

The Energy Systems Laboratory is a teaching and research facility dedicated to the study of energy conversion systems. The lab includes three dynamometers for engine testing, a computer-controlled variable engine valve controller, a fuel-cell experimental station, a small rocket testing facility, and a small jet engine thrust stand.

The Guidance and Control Laboratory, a joint activity of the Department of Aeronautics and Astronautics and the Department of Mechanical Engineering, specializes in construction of electromechanical systems and instrumentation, particularly where high precision is a factor. Work ranges from robotics for manufacturing to feedback control of fuel injection systems for automotive emission control. The faculty and staff work in close cooperation with both the Design and Thermosciences Groups on device development projects of mutual interest.

Many computation facilities are available to department students. Three of the department's labs are equipped with super-minicomputers. Numerous smaller minicomputers and microcomputers are used in the research and teaching laboratories.

Library facilities at Stanford beyond the general library include Engineering, Mathematics, and Physics department libraries.

Mechanical Engineering Course Catalog Numbering System

The department uses the following course numbering system:

Number	Level
001-099	Freshman and Sophomore
100-199	Junior and Senior
200-299	Advanced Undergraduate and Beginning Graduate
300-399	Graduate
400-499	Advanced Graduate
500	Ph.D. Thesis

Bachelor of Science in Mechanical Engineering

The mission of the undergraduate program in Mechanical Engineering is to provide students with a balance of theoretical and practical experiences that enable them to address a variety of societal needs, from more efficient engines and new forms of mobility, to greater access to medical and health services in developing countries. The curriculum encompasses elements from a wide range of disciplines built around the themes of computational engineering, design, energy, materials, mechanics and dynamic systems, consistently considering these topics in their larger societal and professional context. Course work may include mechatronics, computational simulation, solid mechanics, fluid dynamics, electromechanical systems, biomechanical engineering, energy science and technology, sensing and control, and design. The Program prepares students for entry-level work as mechanical engineers and for graduate studies in either an engineering discipline or other fields where a broad engineering background is useful.

Grade Requirements

To be recommended by the department for a B.S. in Mechanical Engineering, a student must achieve the minimum grade point average (GPA) set by the School of Engineering (2.0 in engineering fundamentals and mechanical engineering depth).

Students interested in the minor should see the "Minor in Mechanical Engineering" section of this bulletin.

Mechanical Engineering (ME)

Completion of the undergraduate program in Mechanical Engineering leads to the conferral of the Bachelor of Science in Mechanical Engineering.

Mission of the Undergraduate Program in Mechanical Engineering

The mission of the undergraduate program in Mechanical Engineering is to provide students with a balance of theoretical and practical experiences that enable them to address a variety of societal needs. The curriculum encompasses elements from a wide range of disciplines built around the themes of biomedicine, computational engineering, design, energy, and multiscale engineering. Course work may include mechatronics, computational simulation, solid and fluid dynamics, microelectromechanical systems, biomechanical engineering, energy science and technology, propulsion, sensing and control, nano- and micro- mechanics, and design. The program prepares students for entry-level work as mechanical engineers and for graduate studies in either an engineering discipline or other fields where a broad engineering background is useful.

Core Requirements

		Units
Mathematics		
24 units minimum; see Basic Requirement 1 [1]		
CME 102/ENGR 155A	Ordinary Differential Equations for Engineers	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
Select one of the following:		3-5
CME 106/ ENGR 155C	Introduction to Probability and Statistics for Engineers	
STATS 110	Statistical Methods in Engineering and the Physical Sciences	
STATS 116	Theory of Probability	
Plus additional courses to total min. 24		
Science		
20 units minimum; see Basic Requirement 2 [1]		
Plus addtional required courses [1]		
CHEM 31M	Chemical Principles: From Molecules to Solids	5
Technology in Society		
One course required; TIS courses should be selected from AA 252, BIOE 131, COMM 120W, CS 181, ENGR 131, HUMBIO 174, ME 267, or MSE 193.		3-5
Engineering Fundamentals		
Two courses minimum; see Basic Requirement 3		
ENGR 14	Intro to Solid Mechanics	3
CS 106A	Programming Methodology	5
or CS 106B	Programming Abstractions	
Engineering Core		
Minimum of 68 Engineering Science and Design ABET units; see Basic Requirement 5		
ME 1	Introduction to Mechanical Engineering	3
ENGR 15	Dynamics	3
ME 80	Mechanics of Materials	3
ME 30	Engineering Thermodynamics	3
ME 70	Introductory Fluids Engineering	3
ME 102	Foundations of Product Realization	3
ME 103	Product Realization: Design and Making	4
ME 104	Mechanical Systems Design	4
ME 131	Heat Transfer	4
ME 123	Computational Engineering	4
ME 170A	Mechanical Engineering Design- Integrating Context with Engineering [2,3]	4
ME 170B	Mechanical Engineering Design: Integrating Context with Engineering [2,3]	4

Core Concentrations and Concentration Electives

In addition to completing core requirements, students must choose one of the concentrations paths below. In addition to their concentration specific 3-courses, students select 2-3 additional courses such that the combination adds up to a minimum of 18 units. One of these additional courses must be from technical electives associated with the student's selected concentration. The other 1-2 courses could come from either technical electives from the student's selected concentration or any other concentration and its associated technical electives. Up to 3 units of ME 191 Engineering Problems and Experimental Investigation may be petitioned to count as technical elective.

For students choosing the Materials and Structures concentration path, in addition to the 2 concentration-specific courses, students must select at least 2 courses from the Materials and Structures electives, in addition to courses from other concentrations, as technical electives.

		Units
Dynamic Systems and Controls Concentration		
ME 161	Dynamic Systems, Vibrations and Control	3
ENGR 105	Feedback Control Design	3
Pick one of:		
ME 227	Vehicle Dynamics and Control	3
ME 327	Design and Control of Haptic Systems (not offered AY21)	3
Dynamic Systems and Controls Electives		
ENGR 205	Introduction to Control Design Techniques	3
ME 210	Introduction to Mechatronics (not offered AY21)	4

ME 220	Introduction to Sensors	4
ME 331A	Advanced Dynamics & Computation (not offered AY21)	3
ME 485	Modeling and Simulation of Human Movement	3
Pick one, if not used in concentration already:		
ME 227	Vehicle Dynamics and Control	3
ME 327	Design and Control of Haptic Systems (not offered AY21)	3

		Units
Materials and Structures Concentration		
ME 149	Mechanical Measurements	3
ME 152	Material Behaviors and Failure Prediction	3
Materials and Structures Electives		
(2 M&S electives required for students in M&S concentration)		
AA 240	Analysis of Structures	3
MATSCI 198	Mechanical Properties of Materials	3-4
ME 234	Introduction to Neuromechanics (not offered AY21)	3
ME 241	Mechanical Behavior of Nanomaterials (not offered AY21)	3
ME 281	Biomechanics of Movement	3
ME 283	Introduction to Biomechanics and Mechanobiology (not offered AY21)	3
ME 287	Mechanics of Biological Tissues (not offered AY21)	4
ME 331A	Advanced Dynamics & Computation (not offered AY21)	3
ME 335A	Finite Element Analysis	3
ME 338	Continuum Mechanics	3
ME 339	Introduction to parallel computing using MPI, openMP, and CUDA	3
ME 345	Fatigue Design and Analysis	3
ME 348	Experimental Stress Analysis	3

		Units
Product Realization Concentration		
ME 127	Design for Additive Manufacturing	3
ME 128	Computer-Aided Product Realization	3
ME 129	Manufacturing Processes and Design (offered AY 19-20)	3
Product Realization Electives		
ENGR 110	Perspectives in Assistive Technology (ENGR 110)	1-2
ENGR 240	Introduction to Micro and Nano Electromechanical Systems	3
ME 181	Deliverables: A Mechanical Engineering Design Practicum	3
CME 106	Introduction to Probability and Statistics for Engineers	4
ME 210	Introduction to Mechatronics (not offered AY21)	4
ME 263	The Chair	3-4
or ME 298	Silversmithing and Design	
ME 309	(not offered AY21)	3
ME 324	Precision Engineering	4

		Units
Thermo, Fluids, and Heat Transfer Concentration		
ME 149	Mechanical Measurements	3
ME 132	Intermediate Thermodynamics	4
ME 133	Intermediate Fluid Mechanics	3
Thermo, Fluids, and Heat Transfer Electives		
ME 257	Gas-Turbine Design Analysis (not offered AY21)	3
ME 351A	Fluid Mechanics	3
ME 351B	Fluid Mechanics	3
ME 352B	Fundamentals of Heat Conduction (not offered AY21)	3
ME 352C	Convective Heat Transfer (not offered AY21)	3
ME 352D	Nanoscale heat, mass and charge transport	3
ME 362A	Physical Gas Dynamics	3
ME 370A	Energy Systems I: Thermodynamics	3
ME 370B	Energy Systems II: Modeling and Advanced Concepts	4
ME 371	Combustion Fundamentals	3
AA 283	Aircraft and Rocket Propulsion	3

[1] Math and science must total 45 units.
- Math: 24 units required and must include a course in differential equations (CME 102 Ordinary Differential Equations for Engineers or MATH 53 Ordinary Differential Equations with Linear Algebra; one of these required) and calculus-based Statistics (CME 106 Introduction to Probability and Statistics for Engineers or STATS 110 Statistical Methods in Engineering and the Physical Sciences or STATS 116 is required.
- Science: 20 units minimum and requires courses in calculus-based Physics and Chemistry, with at least a full year (3 courses) in one or the other. CHEM 31A Chemical Principles I/CHEM 31B Chemical Principles II are considered one course because they cover the same material as CHEM 31M but at a slower pace. CHEM 31M is recommended.

[2] ME 170A and ME 170B fulfill the WIM requirement. In AY 2020-21, the same grading basis applies to both ME 170A and ME 170B, and cannot be changed after week 8 of enrollment in ME 170A.

[3] ME 170A (http://exploredegrees.stanford.edu/search/?P=ME%20170A) and ME 170B (http://exploredegrees.stanford.edu/search/?P=ME%20170B) are a two quarter Capstone Design Sequence and must be taken in consecutive quarters.

[4] A course may only be counted towards one requirement; it may not be double-counted. All courses taken for the major must be taken for a letter grade if that option is offered by the instructor. Minimum combined GPA for all courses in Engineering Topics (Engineering Fundamentals and Depth courses) is 2.0.

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu).

BSME 1.0 Notes

Those students (primarily seniors) who are completing BSME 1.0 from AY 2017-2018 or earlier should refer to bulletins from the academic year that corresponds with their program sheet.

Honors Program in Mechanical Engineering

The Department of Mechanical Engineering offers a program leading to a B.S. in Mechanical Engineering with honors. This program offers a unique opportunity for qualified undergraduate engineering majors to conduct independent study and research at an advanced level with a faculty mentor.

Mechanical Engineering majors who have a grade point average (GPA) of 3.5 or higher in the major may apply for the honors program. Students who meet the eligibility requirement and wish to be considered for the honors program must submit a written application to the Mechanical Engineering student services office no later than the second week of Autumn Quarter in the senior year. The application to enter the program can be obtained from the ME student services office, and must contain a one-page statement describing the research topic and include an unofficial Stanford transcript. In addition, the application must be approved by a Mechanical Engineering faculty member who agrees to serve as the thesis adviser for the project. Thesis advisers must be members of Stanford's Academic Council.

In order to receive departmental honors, students admitted to the program must:

1. Maintain the 3.5 GPA required for admission to the honors program.
2. Submit a completed thesis draft to the adviser by the 3rd week of the quarter they intend to confer. Further revisions and final endorsement by the adviser are to be finished by week 6, when two bound copies are to be submitted to the Mechanical Engineering student services office.
3. Present the thesis at the Mechanical Engineering Poster Session held in mid-April. If the poster session is not offered or the student does not confer in the spring, an alternative presentation will be approved on a case by case basis with advisor and UGCC chair approval.

Note: Students may not use work completed towards an honors degree to satisfy the B.S. in ME course requirements.

Mechanical Engineering (ME) Minor

The following courses fulfill the minor requirements:

		Units
General Minor *		
ENGR 14	Intro to Solid Mechanics	3
ENGR 15	Dynamics	3
ME 1	Introduction to Mechanical Engineering	3
ME 30	Engineering Thermodynamics	3
ME 70	Introductory Fluids Engineering	3
Plus two of the following:		
ME 80	Mechanics of Materials	3
ME 102	Foundations of Product Realization	3
ME 131	Heat Transfer	4
ME 161	Dynamic Systems, Vibrations and Control	3
Total Units: 21		
Thermosciences Minor **		
ENGR 14	Intro to Solid Mechanics	3
ME 30	Engineering Thermodynamics	3
ME 70	Introductory Fluids Engineering	3
ME 131	Heat Transfer	4
ME 132	Intermediate Thermodynamics	4
ME 133	Intermediate Fluid Mechanics (offered SPR 18-19; more information to come)	3
ME 149	Mechanical Measurements	3
Total units: 23		
Mechanical Design Minor ***		
ENGR 14	Intro to Solid Mechanics	3
ME 80	Mechanics of Materials	3
ME 1	Introduction to Mechanical Engineering	3
ME 102	Foundations of Product Realization	3
ME 103	Product Realization: Design and Making	4
ME 104	Mechanical Systems Design	4
Plus one of the following:		
ME 127	Design for Additive Manufacturing	3
ME 128	Computer-Aided Product Realization	3-4
ME 129	Manufacturing Processes and Design	3
ME 210	Introduction to Mechatronics	4
ME 220	Introduction to Sensors	3-4
Total units: 23		

* This minor aims to expose students to the breadth of ME in terms of topics and analytic and design activities. Prerequisites: MATH 19 Calculus, MATH 20 Calculus, MATH 21 Calculus, and PHYSICS 41 Mechanics or PHYSICS 41E Mechanics, Concepts, Calculations, and Context.

** Prerequisites: MATH 19 Calculus, MATH 20 Calculus, MATH 21 Calculus , MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications (or CME 100 Vector Calculus for Engineers) and PHYSICS 41 Mechanics or PHYSICS 41E Mechanics, Concepts, Calculations, and Context.

*** This minor aims to expose students to design activities supported by analysis. Prerequisites: MATH 19 Calculus, MATH 20 Calculus, MATH 21 Calculus,PHYSICS 42 Classical Mechanics Laboratory, and PHYSICS 41 Mechanics or PHYSICS 41E Mechanics, Concepts, Calculations, and Context.

Coterminal Master of Science Program in Mechanical Engineering

Stanford undergraduates who wish to continue their studies for the master of science degree in the coterminal program must have earned a minimum of 120 units towards graduation. This includes allowable Advanced Placement (AP) and transfer credit.

Applicants must submit the Coterminal Online Application (https://applyweb.com/stanterm/) no later than the quarter prior to the expected completion of their undergraduate degree. This is normally Winter Quarter (mid January) prior to Spring Quarter graduation. The application must provide evidence of potential for strong academic performance as a graduate student. The Mechanical Engineering department graduate admissions committee makes decisions on each application. Typically, a GPA of at least 3.5 in engineering, science, and math is expected. Undergraduate coursework should demonstrate adequate preparation for pursuing graduate level study in Mechanical Engineering, which typically includes mathematics through ordinary differential equations (CME102 or Math 53), programming (e.g., CS106A) and several 100+ level engineering courses.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees/)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

return to top (p. 6)

Master of Science in Mechanical Engineering

The basic University requirements for the M.S. degree are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin.

The master's program consists of 45 units of course work taken at Stanford. No thesis is required, although many students become involved in research projects during the master's program, particularly to explore their interests in working towards a Ph.D. degree. Students whose undergraduate backgrounds are entirely devoid of some of the major subject disciplines of engineering (for example, applied mechanics, applied thermodynamics, fluid mechanics, ordinary differential equations) may need to take some undergraduate courses to fill obvious gaps and prepare themselves to take graduate courses in these areas. Such students may require more than three quarters to fulfill the master's degree requirements, as the makeup courses may only be used as unrestricted electives (see item 4 below) in the M.S. degree program. However, it is not the policy to require fulfillment of mechanical engineering B.S. degree requirements to obtain an M.S. degree.

Mechanical Engineering

The master's degree program requires 45 units of course work taken as a graduate student at Stanford. No thesis is required. However, students who want some research experience during the master's program may participate in research or independent study through ME 391 Engineering Problems.

Candidates for the M.S. in Mechanical Engineering are expected to have the approval of the faculty; they must maintain a minimum grade point average (GPA) of 3.0 in the 45 units presented for fulfillment of degree requirements (exclusive of independent study courses). All courses used to fulfill mathematics, depth, breadth, approved electives, and lab studies must be taken for a letter grade (excluding seminars, independent study, and courses for which a letter grade is not an option for any student).

Students falling below a GPA of 2.5 at the end of 20 units may be disqualified from further registration. Students failing to meet the complete degree requirements at the end of 60 units of graduate registration are disqualified from further registration. Courses used to fulfill deficiencies arising from inadequate undergraduate preparation for mechanical engineering graduate work may not be applied to the 45 units required for completion of the MS degree.

Students are encouraged to refer to the most recent *Mechanical Engineering Graduate Student Handbook* provided by the student services office.

Degree requirements

1. *Mathematical Fundamentals:* Two math courses covering two different areas out of: partial differential equations, linear algebra, numerical analysis, and statistics. One area covered by each class must be listed on the MS program sheet. The following courses automatically satisfy the requirement in the indicated area(s):

ME 300A/CME 200	Linear Algebra with Application to Engineering Computations	Linear Algebra
ME 300B/CME 204	Partial Differential Equations in Engineering	Partial Differential Equations
ME 300C/CME 206	Introduction to Numerical Methods for Engineering	Numerical Analysis
CME 302	Numerical Linear Algebra	Linear Algebra, Numerical Analysis
ME 408	Spectral Methods in Computational Physics	Numeric Analysis
ME 470/CEE 362A	Uncertainty Quantification (Not offered AY21)	Numerical Analysis, Statistics
EE 261	The Fourier Transform and Its Applications	Linear Algebra, Numerical Analysis
EE/CME 263	Introduction to Linear Dynamical Systems	Linear Algebra
CME/EE 364A	Convex Optimization I	Linear Algebra, Numerical Analysis
CME 106/ENGR 155C	Introduction to Probability and Statistics for Engineers	Statistics
AA 222/CS 361	Engineering Design Optimization	Linear Algebra, Numerical Analysis
CS 205L	Continuous Mathematical Methods with an Emphasis on Machine Learning	Linear Algebra, Numerical Analysis
STATS/CS 229	Machine Learning	Linear Algebra, Statistics
STATS 200	Introduction to Statistical Inference	Statistics
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	Statistics

The Mathematical Fundamentals requirement excludes programming classes such as CS 106A/CS 106B/CS 106X, CME 211, CME 212, CME 213, CME 214, and CME 292. Likewise, MATH or CME courses that address applications of mathematics but are not primarily focused on mathematical fundamentals (e.g., MATH 275, CME 285) are excluded. These classes can be placed in the approved electives category. Other MATH and CME courses with catalog numbers greater than 200 that focus on one or more of the four required areas, such that at least two different areas are covered, can be approved by advisors. Students with questions about their math curriculum covering two different areas should check the course descriptions and consult with their advisor.

2. *Depth in Mechanical Engineering:* Depth refers to a cluster of courses with thematic and/or technical continuity that enables a student to study a part of mechanical engineering in more depth, with more focus, and over a period of time. A depth cluster or area typically is made up of 9 units (2-3 courses). These courses have been approved by the faculty as providing depth in specific areas as well as a significant component of applications of the material in the context of engineering synthesis. The depth areas are outlined in the *Depth and Breadth Areas for the MSME Degree* section Below.
3. *Breadth in Mechanical Engineering:* "Breadth" refers to graduate level ME courses outside of the student's depth area. The intent is for students to engage in course work in areas of mechanical engineering outside of the depth to broaden understanding and competency in a wider range of topics. Two courses are required from the list of eligible breadth courses described under each depth area outlined in the *Depth and Breadth Areas for the MSME Degree* section below.
4. *Sufficient Mechanical Engineering Course Work:* Students must take a minimum of 24 units of coursework in mechanical engineering topics. For the purposes of determining mechanical engineering topics, any course on approved lists for the math requirement, depth requirement, and breadth requirement counts towards these units. In addition, any graduate level course with an ME course number is considered a mechanical engineering topic. Research (independent study) units cannot count towards the 24 units of ME coursework.
5. *Approved Electives:* Additional graduate (numbered 200+) engineering, math, and science courses bring the total number of units to at least 39. All of these units must be approved by the student's advisor. Graduate engineering, math, and science courses are normally approved. 100-level CS courses that satisfy the M.S. in Computer Science program are also allowed. Of these 39 units, no more than 6 units may come from independent study (ME 391 and ME 392) and no more than 3 units may come from seminars. A student planning to continue for a Ph.D. should have a discussion with the academic advisor about taking ME 391 or ME 392 during the master's program. ME 491 and ME 492 may not be included in approved electives. Students may use one of the following courses as an approved elective, without petition: CS 106A, CS 106B, CS 106X, CS 107. Approved electives must be taken for a letter grade unless grades are not an option (e.g., seminars and ME 391 and ME 392), and except those taken during Spring 2020 and academic year 2020-21. Students participating in ME 391 or ME 392 should make the necessary arrangements with a member of the faculty. In addition, the faculty member and the student should determine the number of units for the course. ME 391 and ME3 92 may only be taken on a satisfactory/no credit (S/NC) grading basis. If a student takes an independent study in a different department, the grading option should be credit/no credit.
6. *Unrestricted Electives:* These courses bring the total number of units submitted for the M.S. degree to 45. Students are strongly encouraged to take these units outside of engineering, mathematics, or the sciences. Students should consult their advisor for recommendations on course loads and on ways to use the unrestricted electives to make a manageable program. Unrestricted electives must be level 100+ and may be taken credit/no credit.
7. *Laboratory Requirement:* Within the courses satisfying the requirements above, there must be at least one graduate-level course with a laboratory component. Courses which satisfy this requirement are:

		Units
ME 203	Design and Manufacturing	4
ME 210	Introduction to Mechatronics	4
ME 218A	Smart Product Design Fundamentals	4-5
ME 218B	Smart Product Design Applications	4-5
ME 218C	Smart Product Design Practice	4-5
ME 218D	Smart Product Design: Projects	3-4
ME 220	Introduction to Sensors	4
ME 227	Vehicle Dynamics and Control	3
ME 287	Mechanics of Biological Tissues (not offered 2020-21)	4
ME 310A	Global Engineering Design Thinking, Innovation, and Entrepreneurship	4
ME 310B	Global Engineering Design Thinking, Innovation, and Entrepreneurship	4
ME 310C	Global Engineering Design Thinking, Innovation, and Entrepreneurship	4
ME 318	Computer-Aided Product Creation	4
ME 324	Precision Engineering	4
ME 327	Design and Control of Haptic Systems (not offered 2020-21)	3
ME 328	Medical Robotics	3
ME 348	Experimental Stress Analysis	3
ME 354	Experimental Methods in Fluid Mechanics (Not offered AY21)	4
ME 367	Optical Diagnostics and Spectroscopy Laboratory	4
ME 391	Engineering Problems	1-10
ME 392	Experimental Investigation of Engineering Problems	1-10
ME 398	Ph.D. Research Rotation	1-4
And similar directed study/research courses offered by faculty in other departments will satisfy this requirement if 3 units are taken for work involving laboratory experiments.		
AA 274B/ CS 237B/ EE260B	Principles of Robot Autonomy II	3-4
CS 225A	Experimental Robotics	3

return to top (p. 6)

Depth and Breadth Areas for the MSME Degree

Depth - Select one area as your specialty

Breadth - Select two courses (6 units) from area(s) outside your depth, as noted in each depth area description. They can come from the same area or two different areas.

1. Automatic Controls

(any three of the following):		
AA 203	Optimal and Learning-based Control	3
AA 212	Advanced Feedback Control Design	3
EE 266	Introduction to Stochastic Control with Applications	3
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
ENGR 209A	Analysis and Control of Nonlinear Systems	3
Breadth: If depth is Automatic Controls, select any two courses (6 units) from one or two of the other areas. If depth is other than Automatic Controls, select any course(s) from the list above, or CS333 (Algorithms for Interactive Robotics).		

2. Biomechanical Engineering

Three courses totaling at least 9 units are required, and must include at least two Foundational Courses.		
Foundational Courses		
ME 244	Mechanotransduction in Cells and Tissues	3
ME 281	Biomechanics of Movement (Not offered AY21)	3

ME 283	Introduction to Biomechanics and Mechanobiology (Not offered AY21)	3
ME 287	Mechanics of Biological Tissues (Not offered AY21)	4
ME 337	Mechanics of Growth	3
System-Specific Courses		
ME 234	Introduction to Neuromechanics (Not offered AY21)	3
ME 285	Computational Modeling in the Cardiovascular System	3
ME 328	Medical Robotics	3
ME 380	Current Topics in Exoskeleton and Prosthesis Research	3
ME 381	Orthopaedic Bioengineering	3
ME 485	Modeling and Simulation of Human Movement	3
Breadth: If depth is Biomechanical Engineering, select any two courses (6 units) from one or two of the other areas. If depth is other than Biomechanical Engineering, select any course(s) from the list above.		

Master of Science in Engineering (no field designation)

As described in the "School of Engineering (http://exploredegrees.stanford.edu/schoolofengineering/#masterstext)" section of this bulletin, each department in the school may sponsor students in a more general degree, the M.S. in Engineering. Sponsorship by the Department of Mechanical Engineering (ME) requires:

1. filing a petition for admission to the program by no later than the day before instruction begins.
2. that the center of gravity of the proposed program lies in ME.
3. No more than 18 units used for the proposed program may have been previously completed.
4. The program must include at least 9 units of graduate-level work in the department other than ME 300A,B,C, seminars, and independent study.
5. The petition must be accompanied by a statement explaining the program objectives and how it is coherent, contains depth, and fulfills a well-defined career objective.

The grade requirements are the same as for the M.S. in Mechanical Engineering.

return to top (p. 6)

Master of Science in Engineering, Biomechanical Engineering

The Master of Science in Engineering: Biomechanical Engineering (MSE:BME) promotes the integration of engineering mechanics and design with the life sciences. Applicants are expected to have an additional exposure to biology and/or bioengineering in their undergraduate studies. Students planning for subsequent medical school studies are advised to contact Stanford's Premedical Advising Office in Sweet Hall.

Students wishing to pursue this program must complete the Graduate Program Authorization form and get approval from the Student Services Office. This form serves to officially add the field to the student's record. This form must be filled out electronically on Axess. The Mechanical Engineering Department does not have a coterminal Biomechanical Engineering Master's program.

Degree Requirements

All courses except unrestricted electives must be taken for a letter grade unless letter grades are not an option. A minimum cumulative GPA of 3.0 is required for degree conferral.

1. Mathematical competence (min 6 units) in two of the following areas: partial differential equations, linear algebra, complex variables, or numerical analysis, as demonstrated by completion of two appropriate courses from the following list: ME300A, ME300B, ME300C, MATH106, MATH109, MATH113, MATH131P, STATS110 or ENGR155C, CME108, CME302. Students who have completed comparable graduate-level courses as an undergraduate, and who can demonstrate their competence to the satisfaction of the instructors of the Stanford courses, may be waived via petition from this requirement by their advisor and the Student Services Office. The approved equivalent courses should be placed in the "approved electives" category of the program proposal.
2. Graduate Level Engineering Courses (minimum 21 units), consisting of:
   a. Biomechanical engineering restricted electives (9 units) to be chosen from:

		Units
ME 234	Introduction to Neuromechanics (Not offered AY21)	3
ME 244	Mechanotransduction in Cells and Tissues	3
ME 281	Biomechanics of Movement	3
ME 283	Introduction to Biomechanics and Mechanobiology (Not offered AY21)	3
ME 285	Computational Modeling in the Cardiovascular System	3
ME 287	Mechanics of Biological Tissues (Not offered AY21)	4
ME 328	Medical Robotics (Not offered AY21)	3
ME 337	Mechanics of Growth (Not offered AY21)	3
ME 380	Current Topics in Exoskeleton and Prosthesis Research (Not offered AY21)	3
ME 381	Orthopaedic Bioengineering	3
ME 485	Modeling and Simulation of Human Movement	3

   b. Specialty in engineering (9-12 units): A set of three or four graduate level courses in engineering mechanics, materials, controls, or design (excluding bioengineering courses) selected to provide depth in one area. Comparable specialty sets composed of graduate engineering courses outside the Mechanical Engineering Department can be used with the approval of the student's advisor.
   c. Graduate engineering electives (to bring the total number of graduate level engineering units to at least 21. These electives must contribute to a cohesive degree program, and be approved by the student's advisor. No units may come from bioengineering courses, mathematics courses, or seminars.
3. Life science approved electives (minimum 6 units): Undergraduate or graduate biological/medical science/chemistry courses which contribute to a cohesive program.
4. Biomechanical Research Symposium (ME 389).
5. General approved electives (to bring the total number of units to 39): These courses must be approved by the student's advisor. Graduate level engineering, math, physical science courses and upper

division undergraduate or graduate life science courses are normally approved.

6. Unrestricted electives (to bring the total number of units to 45): Students without undergraduate biology are encouraged to use some of these unrestricted units to strengthen their biology background. Students should consult their advisor for recommendations on course loads and on ways to use the unrestricted electives to create a manageable program.

return to top (p. 6)

Master of Science in Engineering, Design Impact

The Master's Program in Design Impact is project-driven, highly immersive, and based on design thinking, the human-centered design process pioneered at Stanford. We teach the process, mindsets and skills needed to lead high-impact design teams. In our work on products, services, systems, and experiences, empathy is our guiding principle. Students completing the two-year program will earn a Master's of Science in Engineering degree with a concentration in Design Impact (MSE-Design Impact).

The Master's Program in Design Impact is a distinct degree from the MS Mechanical Engineering discipline with a separate application process. You can learn more about the application procedure by navigating to the "How to Apply" page at http://designimpact.stanford.edu/.

Degree Requirements

Candidates for the Design Impact Engineering master's degree are expected to have the approval to graduate from the faculty and a minimum GPA of 3.0 on the 53 units completed in the program.

All required classes and electives must be taken for a letter grade unless:

1. The class is not offered for a letter grade, or
2. Prior approval has been granted to take a class CR/NC in the form of a signed petition filed and approved before the class begins.

In the first year, students take all their classes together as a cohort. In the second year, students will continue to work together in the year-long "Design Impact" course (ME316A, B, C: Design Master's Project), each selecting to work on a project related to one of the two Impact themes. This sequence of classes will be the culmination of their educational experience and launch them into their individual careers as designers.

The student selects electives in the second year with their advisor. The electives are of two types: focused on building a deep learning in the student's chosen Impact theme area and expanding the student's skill set and design toolkit. Students may choose elective courses at the 100 level or higher, in consultation with their advisor, from any of the Schools at the University to fulfill their elective requirement. Electives must be selected to fulfill education and career objectives and be related to their selected theme area within the Design Impact program. The advisor must sign off on a program sheet containing proposed electives prior to the students committing to taking them.

		Units
ME 313	Human Values and Innovation in Design	3
ME 203	Design and Manufacturing [1]	4
ME 277	Graduate Design Research Techniques	3-4
CS 106A	Programming Methodology [2]	3
or higher numbered CS course		
ME 391	Engineering Problems [3]	3
ME 311	Leading Design Teams [4]	3
CS 247A	Design for Artificial Intelligence (or any CS 247 series course, including CS247B, CS247G, CS247I, CS247S)	3 or 4
or CS 347	Human-Computer Interaction: Foundations and Frontiers	
DESINST 215	The Design of Data	3
or CS 448B	Data Visualization	
(Dependent on course selected) Business Considerations in Design [5]		3
ME 316A	Design Impact Master's Project I [6]	2-4
ME 316B	Design Impact Master's Project II [6]	2-4
ME 316C	Design Impact Master's Project III [6]	2-4
ME 391	Engineering Problems [7]	1 or 2
Approved Elective Units [8]		12

1. ME 203 Design and Manufacturing should be completed in the first year, Autumn Quarter of the degree program.
2. CS 106A is for students who have had limited exposure to computer programming and want to start at the introductory level. Students who have already had an introduction to computer science, or who have professional programming experience, should consult with their advisor on the best-fit computer science class; it must have a higher number than 106. Taking a higher-level CS course does not require a petition.
3. ME391 (3 units) will focus on Design Analytics with Lecturer Mark Schar. This is to be completed in the Winter quarter of the student's first year of studies.
4. May substitute with ME 368 d.Leadership: Leading Disruptive Innovation .
5. A course that teaches Business Considerations in Design will be selected by the student in consultation with their advisor. Options include MS&E 140 , ACCT 317 Managerial Accounting: Performance Measurement, Compensation, and Governance, or courses offered by the Stanford Graduate School of Business.
6. ME 316A, B & C are taken sequentially for three quarters during the second year. Students may take ONE of ME316 A, B, or C at reduced units of 2 or 3 in order to allow for a larger-unit elective. Only one quarter may be taken at reduced units, and total units for the quarter must be at least 8. This does not require a petition.
7. ME391 (1 or 2 units) will focus on individual Portfolio Design with each student. This is to be completed during the student's second year of students.
8. Students may choose elective courses at the 100 level or higher, in consultation with their advisor, from any of the Schools at the University to fulfill their elective requirement. Electives must be selected to fulfill education and career objectives and be related to their selected theme area within the Design Impact program. The advisor must sign off on a program sheet containing proposed electives prior to the students committing to taking them.

return to top (p. 6)

Degree of Engineer in Mechanical Engineering

The basic University requirements for the degree of Engineer are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin.

This degree requires an additional year of study beyond the M.S. degree and includes a research thesis. The program is designed for students who wish to do professional engineering work upon graduation and who want to engage in more specialized study than is afforded by the master's degree alone.

Admission standards are substantially the same as indicated under the master's degree. However, since thesis supervision is required and the availability of thesis supervisors is limited, admission is not granted until the student has personally engaged a faculty member to supervise a research project. This most often involves a paid research assistantship awarded by individual faculty members (usually from the funds of sponsored research projects under their direction). Thus, individual arrangement between student and faculty is necessary. Students studying for the M.S. degree at Stanford who wish to continue to the Engineer degree ordinarily make such arrangements during the M.S. degree program. Students holding master's degrees from other universities are invited to apply and may be admitted providing they are sufficiently well qualified and have made thesis supervision and financial aid arrangements.

Department requirements for the degree include a thesis; up to 18 units of credit are allowed for thesis work (ME 400 Thesis). In addition to the thesis, 27 units of approved advanced course work in mathematics, science, and engineering are expected beyond the requirements for the M.S. degree; the choice of courses is subject to approval of the adviser. Students who have not fulfilled the Stanford M.S. degree requirements are required to do so, with allowance for approximate equivalence of courses taken elsewhere; up to 45 units may be transferable. A total of 90 units is required for degree conferral.

Candidates for the degree must have faculty approval and have a minimum grade point average (GPA) of 3.0 for all courses (exclusive of thesis credit and other independent study courses) taken beyond those required for the master's degree.

return to top (p. 6)

Doctor of Philosophy in Mechanical Engineering

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin.

The Ph.D. degree is intended primarily for students who desire a career in research, advanced development, or teaching; for this type of work, a broad background in mathematics and the engineering sciences, together with intensive study and research experience in a specialized area, are the necessary requisites.

In special situations, Academic Council members who are not members of the department's faculty may serve as the principal dissertation adviser when approved by the department. In such cases, a member of the department faculty must serve as program adviser and as a member of the reading committee, and agree to accept responsibility that department procedures are followed and standards maintained.

Prior to being formally admitted to candidacy for the Ph.D. degree, the student must demonstrate knowledge of engineering fundamentals by passing a qualifying examination. The academic level and subject matter of the examination correspond approximately to the master's program in Mechanical Engineering. Typically, the exam is taken in the second year of a students Ph.D. program. The student is required to have a minimum graduate Stanford GPA of 3.5 to be eligible for the exam (grades from independent study courses are not included in the GPA calculation). More information on the qualifying examination process can be found in the ME Graduate Student Handbook, provided online by the student services office.

Ph.D. candidates must complete a minimum of 21 units (taken for a letter grade) of approved formal course work (excluding research, directed study, and seminars) in advanced study in engineering, math and sciences. In addition to this 21 unit requirement, all Ph.D. candidates should participate each quarter in one of the following (or equivalent) seminars:

		Units
ME 389	Biomechanical Research Symposium	1
ME 395	Seminar in Solid Mechanics	1
ME 397	Design Research Theory and Methodology Seminar	1-3
AA 297	Seminar in Guidance, Navigation, and Control	1
ENGR 298	Seminar in Fluid Mechanics	1
ENGR 311A/311B	Women's Perspectives	1

The department has a breadth requirement for the Ph.D. degree. This may be satisfied either by a formal minor in another department (generally 20 units) or by at least 9 units of course work (outside of the primary research topic) which are approved by the principal dissertation adviser. If a minor is taken, 9 units from the minor requirements can be counted towards the depth requirement.

The Ph.D. dissertation normally represents at least one full year of research work and must be a substantial contribution to the field. Students may register for course credit for dissertation work (ME 500) to help fulfill University academic unit requirements, but there is no minimum limit on registered dissertation units, as long as students are registered in at least 8 units (10 is recommended) per quarter prior to TGR. Candidates should note that only completed course units are counted toward the requirement, so ungraded courses or courses with an "N" grade must be cleared before going TGR. Questions should be directed to the department Student Services office.

The final University oral examination (dissertation defense) is conducted by a committee consisting of a chair from another department and four faculty members of the department or departments with related interests. Usually, the committee includes the candidate's adviser, reading committee members, plus two more faculty. The examination consists of two parts. The first is open to the public and is scheduled as a seminar talk, usually for one of the regular meetings of a seminar series. The second is conducted in private and covers subjects closely related to the dissertation topic.

Ph.D. Minor in Mechanical Engineering

Students who wish a Ph.D. minor in ME should consult with the ME student services office. A minor in ME may be obtained by completing 20 units of approved graduate-level ME courses. Courses approved for the minor must form a coherent program and must be chosen from those satisfying requirement 2 for the M.S. in Mechanical Engineering.

See the *Mechanical Engineering Graduate Student Handbook* produced by the Mechanical Engineering student services office for more information.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (http://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a “credit” or “satisfactory” grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

The Department of Mechanical Engineering counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) towards satisfaction of undergraduate degree requirements that normally require a letter grade.

Other Undergraduate Policies

The Department of Mechanical Engineering encourages students to take courses for letter grades when possible in order to have complete records for use when seeking future opportunities, including employment in industry and students seeking to apply for graduate studies. Per University policy, students can change grading basis through the end of Week 8 in all four quarters this year. Students are encouraged to reach out directly to Degree Progress Officer Priscilla Chan <priscillachan@stanford.edu > for questions about petitions, especially in situations related to COVID-19 policies and grading basis.

Graduate Degree Requirements

Grading

For the *Master of Science in Mechanical Engineering (MSME)* program, the Department of Mechanical Engineering will count courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) that satisfy the Math Fundamentals and Approved Electives requirements. Letter grades are still required for courses taken in academic year 2020-21 that satisfy the Depth and Breadth requirements. Per our previous policy, courses taken in Spring 2020 with an 'S' (satisfactory) are counted towards satisfaction of all graduate degree requirements (including Depth and Breadth) that otherwise require a letter grade. In addition, the laboratory requirement for the M.S. program is cancelled for students enrolled in the MS program during academic academic yearear 2020-21.

For the *Master of Science in Engineering, field designation: Biomechanical Engineering* program, the department will count courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) that satisfy the Mathematical Competence, Graduate Engineering Electives, Life Science Approved Electives, and General Approved Electives requirements. Letter grades are still required for courses taken in academic year 2020-21 that satisfy the Biomechanical Engineering Restricted Electives and Specialty in Engineering requirements. Per our previous policy, courses taken in Spring 2020 with an 'S' (satisfactory) are counted towards satisfaction of all graduate degree requirements (including Biomechanical Engineering Restricted Electives and Specialty in Engineering) that otherwise require a letter grade.

For the *Master of Science in Engineering, field designation: Design Impact* program, the department will count all courses taken in Spring 2020 and academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) toward program requirements.

For the *Master of Science in Engineering, no field designation*, the department requires that a minimum of 9 units of graduate level work in the Department of Mechanical Engineering be taken for a letter grade. Outside of those 9 units, we will count all courses taken in Spring 2020 and academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) toward program requirements.

For the *Ph.D. in Mechanical Engineering (PhDME) program*, the Department of Mechanical Engineering will count up to 11 units of courses taken in Spring 2020 and academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) that satisfy the requirements of the 21 units of approved courses in advanced study beyond the MS degree. The department is awaiting University guidance on online vs. in-person qualifying exams during academic year 2020-21. The 3.5 minimum GPA for taking the qualifying exam still applies; if necessary, Ph.D. advisors can submit a request for GPA waiver at the time of the student’s application to take the qualifying exam.

For the *Degree of Engineer* program, the Department of Mechanical Engineering will count up to 11 units of courses taken in Spring 2020 and academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) that satisfy the requirements of the 27 units of approved coursework beyond the MS degree.

Other Graduate Policies

The Department of Mechanical Engineering encourages students to take courses for letter grades when possible in order to have complete records for use when seeking future opportunities, including employment in industry and faculty jobs, M.S. students seeking to join Ph.D. programs, and Ph.D. students preparing to take the qualifying exam. Per University policy, students can change grading basis through the end of Week 8 in all four quarters this year. Students are encouraged to reach out directly to the Director of Graduate Studies, Allison Okamura <aokamura@stanford.edu>, for questions about petitions, especially in situations related to COVID-19 policies and grading basis.

Graduate Advising Expectations

The Department of Mechanical Engineering (ME) is committed to providing academic advising in support of graduate student scholarly and professional development. This advising relationship is most effective when it entails collaborative and sustained engagement between the advisor and the advisee. As a best practice, the advisor/advisee relationship and expectations of both sides should be periodically discussed and reviewed to ensure mutual understanding. All advisors and the advisee are expected to maintain professionalism and integrity.

Faculty advisors guide graduate students in key areas of their academic career. An academic advisor helps guide student selection of courses and provides help in navigating polices and degree requirements. In the case of faculty advising teaching assistants, the relationship should include help with development of teaching pedagogy and practice. If the advisor also serves as the primary research advisor, then the advising is much more extensive and also includes research training, design, execution, and career planning (see also Ph.D. section below).

In all cases, graduate students should be active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program (including reading the ME Department’s Graduate Student Handbook). Graduate students conducting research should also strive to understand the method and goals of the research and the project’s contribution to the pertinent field.

The faculty Director of Graduate Studies (DGS) meets with all master’s and doctoral students at the start of their first year, and is available year-round via email and by appointment. The department’s Student Services Office is also an important part of the advising team; they inform students and advisors about university and department requirements, procedures, and opportunities, and maintain the official records of advising assignments. Students are encouraged to talk with staff of the Student Services Office, including the DGS, as they consider advisor selection, or for advice in working with their advisor(s). Another excellent resource for students is the ME Graduate Student Committee, a student-run group which organizes social, academic, and community events for the graduate student population in the ME Department.

Master of Science

At the start of graduate study in the master's program, each student is assigned an advisor: a member of the who provides guidance in course selection and in exploring academic opportunities and professional pathways. The graduate student handbook provides a summary of program requirements. Although there is no set rule for meeting frequency, academic advisor and student should meet about once per quarter, particularly during the first few quarters of the student's time at Stanford. Usually, the same faculty member serves as program advisor for the duration of master's study, but a student can seek a change of advisor by contacting the Student Services Office and/or the ME faculty with whom they seek an advisor/student relationship.

Ph.D. and Engineer Degrees

The ME Department provides academic advising in support of doctoral student scholarly and professional development. A successful advisor/advisee relationship is particularly important for students seeking a Ph.D. in the department. The material in this section is also applicable to students seeking the Degree of Engineer.

In addition to the goals listed above for all advisor/advisee relationships, the Ph.D. advisor provides advice and guidance on developing research skills, choosing classes that helps with the student's research, identifying and planning research projects, dissemination/publishing of the research, and exploring academic opportunities and professional pathways. The Ph.D. advisor serves as an intellectual and professional mentor to the Ph.D. student. In some cases, a Ph.D. student may be advised by two or more advisors. In these cases, the various roles and goals of each of these individuals should be made very clear to all involved. For example, the co-advisors in such arrangements should strive to coordinate and provide non-conflicting advice to the student and the advisee should work to improve and facilitate communication with the two advisors and provide feedback to and from their advisors.

In the ME department, Ph.D. students can be admitted to be advised by a specified faculty member, or admitted with a fellowship associated with the research rotation program. For the latter, the student is initially assigned a program advisor by the department. This faculty member provides initial guidance in course selection, in exploring academic opportunities and professional pathways, and in identifying doctoral research opportunities. Students are required to perform rotations until a Ph.D. research advisor is identified, and they are strongly encouraged to explore research activities with two or three different faculty members during their first academic year. All Ph.D. students seeking a Ph.D. research advisor are encouraged to very proactively seek out, meet with, and discuss possibilities for Ph.D. advisors. Ideally, these discussions should include possible research projects and the possibility for and sources of sustained research funding.

Ph.D. students must identify their doctoral research/thesis advisor (and vice versa) prior to the end of the first year of study. Ideally, this should happen with the first 9 to 10 months. The research supervisor assumes primary responsibility for the future direction of the student, taking on the roles previously filled by the program advisor as well as the aforementioned research-related advice, and ultimately directing the student's dissertation. Most ME Ph.D. students find an advisor from among the primary faculty members of the department. However, the research advisor may be a qualified faculty member from another Stanford department who is able to provide both advising and funding for the duration of the doctoral program**.** When the research advisor is from outside the department, the student must also identify a program advisor, called a co-advisor, from the primary ME faculty, to provide guidance on departmental requirements and opportunities. The co-advisor is also a member of the student's dissertation reading committee.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Emeriti: (Professors) James L. Adams, Thomas P. Andriacchi, David M. Barnett, Peter Bradshaw, Brian J. Cantwell, Dennis R. Carter, Daniel B. DeBra, Robert H. Eustis, Thomas J. R. Hughes, James P. Johnston, Thomas R. Kane, William M. Kays, Joseph B. Keller, Charles H. Kruger, Robert H. McKim, Robert J. Moffat, M. Godfrey Mungal, J. David Powell, Charles R. Steele*, Douglass J. Wilde; *(Professors, Research)* Richard M. Christensen, Sidney A. Self, Kenneth J. Waldron*, Felix E. Zajac

Chair: Ellen Kuhl

Director of Graduate Studies: Allison Okamura

Director of Undergraduate Studies: Mark Cappelli

Group Chairs: Mark R. Cutkosky & Sheri D. Sheppard (Design), Marc Levenston (Biomechanical Engineering), Gianluca Iaccarino & Parviz Moin (Flow Physics and Computational Engineering), Wei Cai (Mechanics and Computation), Christopher F. Edwards (Thermosciences)

Professors: Craig T. Bowman, Mark A. Cappelli, Mark R. Cutkosky, John Dabiri, Scott L. Delp, John K. Eaton, Christopher F. Edwards, Charbel Farhat, J. Christian Gerdes, Kenneth E. Goodson, Ronald K. Hanson, Gianluca Iaccarino, David M. Kelley, Thomas W. Kenny, Ellen Kuhl, Larry J. Leifer, Sanjiva K. Lele, Arun Majumdar, Reginald E. Mitchell, Parviz Moin, Drew V. Nelson, Allison M. Okamura, Peter M. Pinsky, Friedrich B. Prinz, Beth L. Pruitt, Bernard Roth, Juan G. Santiago, Eric S. G. Shaqfeh, Sheri D. Sheppard, Hai Wang

Associate Professors: Wei Cai, Steve Collins, Eric F. Darve, W. Matthias Ihme, Marc E. Levenston, Adrian J. Lew, Ali Mani, Xiaolin Zheng

Assistant Professors: Ovijit Chaudhuri, Sean Follmer, Wendy Gu, David Lentink, Erin MacDonald, Sindy K.-Y. Tang

Professor (Teaching): David W. Beach

Courtesy Professors: Oussama Khatib, Paul Yock

Courtesy Associate Professor: Nicholas Giori, Christian Linder

Courtesy Assistant Professor: David Camarillo, Roseanna Zia

Senior Lecturers: Vadim Khayms, J. Craig Milroy

Adjunct Professors: Mehdi Asheghi, Michael R. Barry, William R. Burnett, J. Edward Carryer, Rainer J. Fasching, Shannon Gilmartin, John A. Howard, Barry M. Katz, Paul Mitiguy, Gary O'Brien, Dev Patnaik, Paul Saffo III, George Toye

* Recalled to active duty.

Cognate Courses

		Units
CS 106A	Programming Methodology	3-5
CS 223A	Introduction to Robotics	3
ENGR 14	Intro to Solid Mechanics	3
ENGR 15	Dynamics	3
ENGR 40		
ENGR 105	Feedback Control Design	3
ENGR 205	Introduction to Control Design Techniques	3
ENGR 209A	Analysis and Control of Nonlinear Systems	3
ENGR 240	Introduction to Micro and Nano Electromechanical Systems	3

ENGR 341	Micro/Nano Systems Design and Fabrication	3-5

Overseas Studies Courses in Mechanical Engineering

The Bing Overseas Studies Program (http://bosp.stanford.edu) (BOSP) manages Stanford international and domestic study away programs for Stanford undergraduates. Students should consult their department or program's student services office for applicability of Overseas Studies courses to a major or minor program.

The BOSP course search site (https://undergrad.stanford.edu/programs/bosp/explore/search-courses/) displays courses, locations, and quarters relevant to specific majors.

For course descriptions and additional offerings, see the listings in the Stanford Bulletin's ExploreCourses (http://explorecourses.stanford.edu) or Bing Overseas Studies (http://bosp.stanford.edu).

Due to COVID-19, all BOSP programs have been suspended for Autumn Quarter 2020-21. All courses and quarters of operation are subject to change.

		Units
explorecourses:OSP	me	

Courses

ME 1. Introduction to Mechanical Engineering. 3 Units.
This course is intended to be the starting point for Mechanical Engineering majors. It will cover the concepts, engineering methods, and common tools used by mechanical engineers while introducing the students to a few interesting devices. We will discuss how each device was conceived, design challenges that arose, application of analytical tools to the design, and production methods. Main class sections will include lectures, demonstrations, and in-class group exercises. Lab sections will develop specific skills in freehand sketching and computational modeling of engineering systems. Prerequisites: Physics: Mechanics, and first quarter Calculus.

ME 2. Experimental Problem Solving for Engineers. 1 Unit.
Are you curious about how to solve problems and test your designs & creations? This 1-unit course helps students learn how to solve problems using scientific experiments, by designing and implementing a series of simple but scientific experiments in a weekly one-hour class. Join us to break candy, mix coffee, and have fun finding out how to use testing to solve legitimate engineering problems, while learning how to design fair, useful tests for your own projects.

ME 14AX. Design for Silver and Bronze. 2 Units.
This class aims to provide a synthesis of design and technique in metalworking. When using precious metals (silver and bronze) the scale of the works naturally becomes much smaller than other design endeavors. This intimate size allows for attention to detail and refinement not common or often considered in other areas of design. The method involves creating a piece out of wax, and going through a process to achieve that piece in metal. All projects will center on this process. Students will complete complete three projects, a quick-start ring, a client design theme project and a belt.nnSara and Amanda have been teaching ME298: Silversmithing in Design at Stanford for 17 years, they are full time designers at RedStart Design, LLC and also Lecturers in Design in the Mechanical Engineering Department.

ME 15AX. Voluminous Design. 2 Units.
This class aims to provide a synthesis of design and technique in metalworking. When using precious metals (silver and bronze) the scale of the works naturally becomes much smaller than other design endeavors. This intimate size allows for attention to detail and refinement not common or often considered in other areas of design. The method involves creating a piece out of wax, and going through a process to achieve that piece in metal. All projects will center on this process. Students will complete complete three projects, a quick-start ring, a client design theme project and a belt. Sara and Amanda have been teaching ME298: Silversmithing in Design at Stanford for 17 years, they are full time designers at RedStart Design, LLC and also Lecturers in Design in the Mechanical Engineering Department.

ME 17. The Science of Flames. 3 Units.
This course is about what causes flames to look like they do and about what causes them to propagate. The physical and chemical phenomena that govern behaviors of flames will constitute the topics for discussion. The basic principles that govern flame phenomena include the conservation of mass, the first law of thermodynamics, and the momentum principle. Since flame processes are controlled by the rates of chemical reactions, these basic principles will be applied when account is made for the chemical transformations that occur when reactant bonds are broken and new bonds are formed, producing combustion products. In essence, this course serves as an introduction to combustion science.

ME 20N. Haptics: Engineering Touch. 3 Units.
Students in this class will learn how to build, program, and control haptic devices, which are mechatronic devices that allow users to feel virtual or remote environments. In the process, students will gain an appreciation for the capabilities and limitations of human touch, develop an intuitive connection between equations that describe physical interactions and how they feel, and gain practical interdisciplinary engineering skills related to robotics, mechanical engineering, electrical engineering, bioengineering, and computer science. In-class laboratories will give students hands-on experience in assembling mechanical systems, making circuits, programming Arduino microcontrollers, testing their haptic creations, and using Stanford¿s student prototyping facilities. The final project for this class will involve creating a novel haptic device that could be used to enhance human interaction with computers, mobile devices, or remote-controlled robots.

ME 22N. Smart Robots in our Mix: Collaborating in High Tech Environments of Tomorrow. 3 Units.
This course invites students to explore rules of engagement in a global digitally interconnected world they will create with the robots in their society. The material will be taught in the context of ubiquitous integrated technology that will be part of their future reality. Human-robot interactions will be an integral part of future diverse teams. Students will explore what form will this interaction take as an emerging element of tomorrow's society, be it medical implanted technology or the implications of military use of robots and social media in future society. Students will learn to foster their creative confidence to explore collaboration by differences for social innovation in a digitally networked world.

ME 23N. Soft Robots for Humanity. 3 Units.
While traditional robotic manipulators are constructed from rigid links and simple joints, a new generation of robotic devices are soft, using flexible, deformable materials. Students in this class will get hands-on experience building soft robots using various materials, actuators, and programming to create robots that perform different tasks. Through this process, students will gain an appreciation for the capabilities and limitations of bio-inspired systems, use design thinking to create novel robotic solutions, and gain practical interdisciplinary engineering skills.

ME 30. Engineering Thermodynamics. 3 Units.
The basic principles of thermodynamics are introduced in this course. Concepts of energy and entropy from elementary considerations of the microscopic nature of matter are discussed. The principles are applied in thermodynamic analyses directed towards understanding the performances of engineering systems. Methods and problems cover socially responsible economic generation and utilization of energy in central power generation plants, solar systems, refrigeration devices, and automobile, jet and gas-turbine engines.

ME 35SI. Designing Moonshots. 2 Units.
This seminar will bring a small group of motivated students across Stanford's many disciplines in an education experiment in human-centered design and rapid prototyping. Through immersion in intimate conversations with thought leaders and student-led user interviews surrounding some of the most pressing global issues, students will learn to identify unique areas of need and assess the domain-specific landscapes for innovating moonshot projects. Students will apply design, prototyping, and user research in a series of interactive team projects aimed at formulating tangible solutions.

ME 47. Press Play: Interactive Device Design. 4-5 Units.
This course provides an introduction to the human-centered and technical workings behind interactive devices ranging from cell phones and video controllers to household appliances and smart cars. This is a hands-on, lab-based course; there will be no midterm or final. Course topics include electronics prototyping, interface prototyping, sensors and actuators, microcontroller development, physical prototyping and user testing. For the final project, students will build a working MP3 player prototype of their own design, using embedded microcontrollers, digital audio decoders, component sensors and other electronic hardware. Prior experience in programming, such as CS106A (or equivalent) or electronics, such as ENG40A (or equivalent) preferred. Students must attend the first class.

ME 70. Introductory Fluids Engineering. 3 Units.
Elements of fluid mechanics as applied to engineering problems. Equations of motion for incompressible flow. Hydrostatics. Control volume laws for mass, momentum, and energy. Bernoulli equation. Differential equations of fluid flow. Euler equations. Dimensional analysis and similarity. Internal flows. Introductory external boundary layer flows. Introductory lift and drag. ENGR14 and ME30 required.

ME 80. Mechanics of Materials. 3 Units.
Mechanics of materials and deformation of structural members. Topics include stress and deformation analysis under axial loading, torsion and bending, column buckling and pressure vessels. Introduction to stress transformation and multiaxial loading. Prerequisite: ENGR 14.

ME 101. Visual Thinking. 4 Units.
ME101 is at the foundation class for all designers and creative people at Stanford. It teaches you how to access your creativity through a series of projects, all of which have been redesigned so that they can be accomplished in an online learning environment. Visual thinking, a powerful adjunct to other problem solving modalities, is developed and exercised in the context of solving some fun and challenging design problems. Along the way, the class expands you access to your imagination, helps you see more clearly with the "mind's eye:¿, and learn how to do rapid visualization and prototyping. The emphasis on basic creativity, learning to build in the 3D world, and fluent and flexible idea production.

ME 102. Foundations of Product Realization. 3 Units.
Students develop the language and toolset to transform design concepts into tangible models/prototypes that cultivate the emergence of mechanical aptitude. Visual communication tools such as sketching, orthographic projection, and 2D/3D design software are introduced in the context of design and prototyping assignments. Due to COVID-19 restrictions during AY20-21, in-person use of the Product Realization Lab may be limited or not permitted. Lab kits will be sent to enrolled students to support exploration of prototyping and mechanical design techniques that will be practiced during synchronous lectures and coaching sessions. Project documentation, reflection, and presentations are opportunities for students to find their design voice and practice sharing it with others. Prerequisite: ME 1 or ME 101 or consent of instructor.

ME 103. Product Realization: Design and Making. 4 Units.
ME103 will be taught entirely on line. While this has the obvious disadvantage of no physical PR access, we experimented with a recreated version of the course this past spring quarter. On line ME103 delivered excellent educational value. Student response was very positive. The course was a mix of published weekly recorded lectures, small group coaching sessions, a newly developed library of "Technical Notes", and kits of tools and materials given to each student for the purpose of rapid prototyping. We increased emphasis on CAD with good support for Fusion 360 as well as Solid Works. We increased emphasis on manufacturing processes including a redesign of projects assuming scaled manufacturing.

ME 103D. Engineering Drawing and Design. 1 Unit.
Designed to accompany 203. The fundamentals of engineering drawing including orthographic projection, dimensioning, sectioning, exploded and auxiliary views, assembly drawings, and SolidWorks. Homework drawings are of parts fabricated by the student in the lab. Assignments in 203 supported by material in 103D and sequenced on the assumption that the student is enrolled in both courses simultaneously.

ME 104. Mechanical Systems Design. 4 Units.
How to design mechanical systems through iterative application of intuition, brainstorming, analysis, computation and prototype testing. Design of custom mechanical components, selection of common machine elements, and selection of electric motors and transmission elements to meet performance, efficiency and reliability goals. Emphasis on high-performance systems. Independent and team-based design projects. Prerequisites: PHYSICS 41; ENGR 14; ME 80; ME 102; ME 103 or 203. Must have PRL pass. Must attend lecture. Recommended: ENGR 15; CS 106A; ME 128 or ME 318. ME104: We are excited about our new plan for ME 104, and we think students will have a great experience even under these conditions. We'll be changing up the lecture elements of the course, switching to asynchronous videos and small synchronous coaching groups. We *will* have hands-on projects, switching from two larger projects with on-campus fabrication to several smaller projects built at home using the personal 3D printers students in these courses will receive and an ME104-specific kit we'll send out. Some of these changes might even improve the course over the long run . We hope students will come build with us! It should be fun. Steve Collins, stevecollins@stanford.edu.

ME 104B. Designing Your Life. 2 Units.
This course applies the mindsets and innovation principles of design thinking to the "wicked problem" of designing your life and vocation. The course introduces design thinking processes through application: students practice awareness and empathy, define areas of life and work on which hey want to work, ideate about ways to move forward, try small prototypes, and test their assumptions. The course is highly interactive. The course will include brief readings, writing, reflections, and in-class exercises. Expect to practice ideation and prototyping methodologies, decision making practices and to participate in hands on activities in pairs, trios, and small groups. Also includes roleplaying, assigned conversations with off campus professionals, guest speakers, and individual mentoring and coaching. It will conclude with creation of 3 versions of the next 5 years and prototype ideas to begin making those futures a reality. Open to juniors, seniors and 5th year coterms, all majors. All enrolled and waitlisted students should attend class on day 1 for admission. Additional course information at http://www.designingyourlife.org.

ME 104S. Designing Your Stanford. 2 Units.
DYS uses a Design Thinking approach to help Freshmen and Sophomores learn practical tools and ideas to make the most of their Stanford experience. Topics include the purpose of college, major selection, educational and vocational wayfinding, and innovating college outcomes, explored through the design thinking process. This seminar class incorporates small group discussion, in-class activities, field exercises, personal reflection, and individual coaching. Expect ideation tools, storytelling practices, prototyping to discover more about yourself and possible paths forward. The course concludes with creation of multiple versions of what college might look like and how to make those ideas reality. All enrolled and waitlisted students should attend class on day 1 for admission. Additional course information at http://www.designingyourstanford.org.
Same as: EDUC 118S

ME 105. Designing for Impact. 3 Units.
This course will introduce the design thinking process and skills, and explore unique challenges of solving problems and initiating action for public good. Design skills such as need-finding, insight development, and prototyping will be learned through hands-on project work with a community partner and a particular emphasis on the elements required to be effective in the social sector. This is a Cardinal Course certified by the Haas Center for Public Service. ME101 recommended.

ME 110. Design Sketching. 2 Units.
Design Visualization, offers students a unique opportunity to acquire a new (visual) language over the span of one short quarter. nnnImagine a process whereby you can close your eyes, and, after a few short weeks, leveraging established Design Principles, open them, and imagine/draw virtually anything that comes to mind.... this is our pledge to you, independent of your previous sketching experience.nnnThis course melds basics with Industrial Design discipline (which creates the aesthetic, experience of products and services), dividing it into two parts; the ability to representationally draw in three-dimensions, while exploring the nuances of form & materials. ME110 initially focuses on the first component, building the structural foundation for perspective drawing, then introducing basic lighting and shading theory to 'complete the picture'. Analysis gives way to individual choice, as confidence builds. nnnWhile we express & explore solutions with traditional analog medium (pens, paper, etc.;-- supplied!), we bridge 'the digital divide', expressing final projects in several media choices, stirring in portfolio & professional advice enroute.

ME 110B. Digital Design Principles and Applications. 2 Units.
Building upon foundation design principles, project-based individual / group exploration and critique facilitates a self-guided learning process, where analytical problem-solving approaches are cultivated through real-time implementation in digital tools. A series of diverse projects are brought together in conjunction with related student project portfolio development. Class Prerequisites: Students must have completed ME110 with high levels of understanding, engagement. May be repeat for credit.

ME 115A. Introduction to Human Values in Design. 3 Units.
An intensive project-based class that introduces the central philosophy of the product design program. Students learn how to use the lens of human needs to innovate at the intersection of technical factors (feasibility), business factors (viability), and human values (desirability). Students work toward mastery of the human-centered design methodology through several real-world, team-based projects. Students gain fluency in designing solutions ranging from physical products, to digital interfaces, to services and experiences. Students are immersed in building their individual and team capacities around core design process and methods, and emerge with a strong foundation in needfinding, synthesis, ideation, rapid prototyping, user testing, iteration, and storytelling.

ME 115B. Product Design Methods. 4 Units.
This course will introduce the basic concepts of human factors and demonstrate the importance of understanding and considering human capabilities and limits in product and system design. This will include an overview of both cognitive and physical human characteristics, methods to analyze human factors constraints, and design methods for prototyping and evaluating the usability of physical products and systems. In this course individual- and team-based design projects are used to emphasize the integration between human factors analysis and evaluation, authoring design requirements and translating these to both physical products and systems.Prerequisites: ME101, ME115A, ME110. Strongly recommended: ME102, Psych 1.

ME 115C. Designing Your Business. 3 Units.
Designing Your Business: introduces business concepts and personal capabilities to designers critical to the development, launch, and success of new products and services in for-profit and social enterprises. Functionally, students will learn to build the business case for new products, including skills such as market sizing, cost estimation, P&L modeling, and raising capital. In addition, business functions such as marketing, growth, and product management and the role of designers in businesses will be explored through class visitors and case studies. Projects culminating in a final presentation to persuade industry experts will develop teamwork and individual effectiveness in putting all the skills together to persuade and mobilize resources through live presentations, written communications, and videos.

ME 120. History and Ethics of Design. 3 Units.
Those who do not learn from history are doomed to repeat it. In this class we will examine the history of design, the challenges that designers over the ages have had to face and the ethical questions that have arisen from those choices. This class will explore a non-traditional view of design, looking at both the sung and unsung figures of history and question the choices they made, up to and including recent events in the Silicon Valley. Course work will include group projects as well as weekly writing. This course is required for students in Product Design and, as such, priority will be given to these students. If you are not in the Product Design program, instructor permission is needed for enrollment.

ME 123. Computational Engineering. 4 Units.
The design of wind turbines, biomedical devices, jet engines, electronic units, and almost every other engineering system, require the analysis of its flow and thermal characteristics to ensure optimal performance and safety. The continuing growth of computer power and the emergence of general-purpose engineering software has fostered the use of computational analysis as a complement to experimental testing. Virtual prototyping is a staple of modern engineering practice. This course is an introduction to Computational Engineering using commercial analysis codes, covering both theory and applications. Assuming limited knowledge of computational methods, the course starts with introductory training on the software, using a nnseries of lectures and hands-on tutorials. We utilize the ANSYS software suite, which is used across a variety of engineering fields. Herein, the emphasis is on geometry modeling, mesh generation, solution strategy and post-processing for diverse applications. Using classical flow/thermal problems, the course develops the essential concepts of Verification and Validation for engineering simulations, nnproviding the basis for assessing the accuracy of the results. Advanced concepts such as the use of turbulence models, user programming and automation for design are also introduced. The course is concluded by a project, in which the students apply the software to solve a industry-inspired problem. Enrollment priority will be given to juniors and seniors who are using this course to meet their BSME program requirements.

ME 124. Visual Expressions. 3 Units.
A hands-on exploration of the elements and principles of 2D and 3D design common to all the visual arts. Through a mix of theory, analysis, and practice the student will develop his/her ability to interpret visual content and produce effective imagery. Limited enrollment, attendance at first class required.

ME 125. Visual Frontiers. 3 Units.
The student will learn how to use graphic design to communicate online, in person, and through printed matter. Fundamentals of visual communications will be applied to branding exercises, typographic studies, color explorations, drawing exercises, use of photography, and use of grid and layout systems.

ME 127. Design for Additive Manufacturing. 3 Units.
Design for Additive Manufacturing (DfAM) combines the fields of Design for Manufacturability (DfM) and Additive Manufacturing (AM). ME127 will introduce the capabilities and limitations of various AM technologies and apply the principles of DfM in order to design models fit for printing. Students will use Computer Aided Design (CAD) software to create models and run simulations of their designs. Topics include: design for rapid prototyping, material selection, post-processing and finishing, CAD simulation, algorithmic modeling, additive tooling and fixtures, and additive manufacturing at scale. Prerequisite: ME102, ME80, or consent of instructor.

ME 128. Computer-Aided Product Realization. 3-4 Units.
ME128 Computer Aided Product Realization and ME318 Computer Aided Product Creation will continue to be taught contiguously through asynchronous lectures and online synchronous office hours, coaching, and feedback sessions. The one difference is that ME318 students will be brought into the PRL to learn and use the Lab's four Haas VF2 CNC machines during structured labs. For this reason undergrads will not be allowed to enroll in ME318. Students in both classes will be creating designs and subsequent code right up to the point of operating the machine. Our experience from Spring Quarter is that students will receive 85% of the knowledge they normally acquire during an on-campus quarter and we will be adding additional content to bring 100% equivalency to both courses.

ME 129. Manufacturing Processes and Design. 3 Units.
ME129 is intended for mechanical engineering juniors who have elected the Product Realization Concentration.nnnME129 will be taught on-line through Zoom and Canvas resources. There will be weekly, recorded presentations, recorded virtual manufacturing field trips, and sessions devoted to coaching, presentation, and discussion. Students will acquire professional level information and experience with properties of materials and manufacturing processes. We will offer information about, and encourage discussion of, environmental sustainability as a unifying theme throughout. Prerequisite: ME102 and ME103, or consent of instructor.

ME 131. Heat Transfer. 4 Units.
The principles of heat transfer by conduction, convection, and radiation with examples from the engineering of practical devices and systems. Topics include transient and steady conduction, conduction by extended surfaces, boundary layer theory for forced and natural convection, boiling, heat exchangers, and graybody radiative exchange. Prerequisites: ME70, ME30 (formerly listed at ENGR30). Recommended: intermediate calculus, ordinary differential equations.This course was formerly ME131A. Students who have already taken ME131A should not enroll in this course.

ME 131B. Fluid Mechanics: Compressible Flow and Turbomachinery. 4 Units.
Engineering applications involving compressible flow: aircraft and rocket propulsion, power generation; application of mass, momentum, energy and entropy balance to compressible flows; variable area isentropic flow, normal shock waves, adiabatic flow with friction, flow with heat addition. Operation of flow systems: the propulsion system. Turbomachinery: pumps, compressors, turbines. Angular momentum analysis of turbomachine performance, centrifugal and axial flow machines, effect of blade geometry, dimensionless performance of turbomachines; hydraulic turbines; steam turbines; wind turbines. Compressible flow turbomachinery: the aircraft engine. Prerequisites: 70, ENGR 30.

ME 132. Intermediate Thermodynamics. 4 Units.
A second course in engineering thermodynamics. Review of first and second laws, and the state principle. Extension of property treatment to mixtures. Chemical thermodynamics including chemical equilibrium, combustion, and understanding of chemical potential as a driving force. Elementary electrochemical thermodynamics. Coursework includes both theoretical and applied aspects. Applications include modeling and experiments of propulsion systems (turbojet) and electricity generation (PEM fuel cell). Matlab is used for quantitative modeling of complex energy systems with real properties and performance metrics. Prerequisites: ME30 required, ME70 suggested, ME131 desirable.

ME 133. Intermediate Fluid Mechanics. 3 Units.
This course expands on the introduction to fluid mechanics provided by ME70. Topics include the conservation equations and finite volume approaches to flow quantification; engineering applications of the Navier-Stokes equations for viscous fluid flows; flow instability and transition to turbulence, and basic concepts in turbulent flows, including Reynolds averaging; boundary layers, including the governing equations, the integral method, thermal transport, and boundary layer separation; fundamentals of computational fluid dynamics (CFD); basic ideas of one-dimensional compressible flows.

ME 139. Educating Young STEM Thinkers. 3-5 Units.
The course introduces students to the design thinking process, the national conversations about the future of STEM careers, and opportunities to work with middle school students and K-12 teachers in STEM-based after-school activities and intercession camps. The course is both theory and practice focused. The purpose is twofold; to provide reflection and mentoring opportunities for students to learn about pathways to STEM careers and to introduce mentoring opportunities with young STEM thinkers.
Same as: EDUC 239, ME 231

ME 140. Advanced Thermal Systems. 5 Units.
Capstone course. Thermal analysis and engineering emphasizing integrating heat transfer, fluid mechanics, and thermodynamics into a unified approach to treating complex systems. Mixtures, humidity, chemical and phase equilibrium, and availability. Labs apply principles through hands-on experience with a turbojet engine, PEM fuel cell, and hybrid solid/oxygen rocket motor. Use of MATLAB as a computational tool. Prerequisites: ENGR 30, ME 70, and 131A,B.

ME 141. Alternative Energy Systems. 5 Units.
Capstone course. Energy analysis, diagnostics and engineering of selected alternative energy systems with an integrated thermodynamic, heat transfer, and fluid mechanic approach. Mixtures, transport, reactions, electrochemical processes and photovoltaic effects. Labs apply principles through hands-on experience with selected alternative energy systems and their components. Use of MATLAB as an analysis tool.

ME 149. Mechanical Measurements. 3 Units.
The Mechanical Measurement experiments course introduces undergraduates to modern experimental methods in solid mechanics, fluid mechanics, and thermal sciences. A key feature of several of the experiments will be the integration of solid mechanics, fluid mechanics, and heat transfer principles, so that students gain an appreciation for the interplay among these disciplines in real-world problems.

ME 151. Introduction to Computational Mechanics. 4 Units.
In modern engineering design of structural systems, computer analysis is often used at every stage, from initial prototyping through final design. This course will introduce students to computational modeling and prototyping applied to solids and structures. The course reviews the basic theory of linear solid mechanics, introduces the finite element method for numerical modeling of mechanics-based problems, and provides practical experience in computer modeling using a commercial finite element code.

ME 152. Material Behaviors and Failure Prediction. 3 Units.
Exploration of mechanical behaviors of natural and engineered materials. Topics include anisotropic, elastoplastic and viscoelastic behaviors, fatigue and multiaxial failure criteria. Applications to biological materials and materials with natural or induced microstructures (e.g., through additive manufacturing). Prerequisite: ME80 or CEE101A.

ME 161. Dynamic Systems, Vibrations and Control. 3 Units.
Modeling, analysis, and measurement of mechanical and electromechanical dynamic systems. Closed form solutions of ordinary differential equations governing the behavior of single and multiple-degree-of-freedom systems. Stability, forcing, resonance, and control system design. Prerequisites: Ordinary differential equations (CME 102 or MATH 53), linear algebra (CME 104 or MATH 53) and dynamics (E 15) are recommended.

ME 170A. Mechanical Engineering Design- Integrating Context with Engineering. 4 Units.
First course of two-quarter capstone sequence. Working in project teams, design and develop an engineering system addressing a real-world problem in theme area of pressing societal need. Learn and utilize industry development process: first quarter focuses on establishing requirements and narrowing to top concept. Second quarter emphasizes implementation and testing. Learn and apply professional communication skills, assess ethics. Students must also enroll in ME170b; completion of 170b required to earn grade in 170a. Course sequence fulfills ME WIM requirement. Prerequisites: ENGR15, ME80, ME104 (112), ME131, ME123/151. (Cardinal Course certified by the Haas Center).

ME 170B. Mechanical Engineering Design: Integrating Context with Engineering. 4 Units.
Second course of two-quarter capstone sequence. Working in project teams, design and develop an engineering system addressing a real-world problem in theme area of pressing societal need. Learn and utilize industry development process: first quarter focuses on establishing requirements and narrowing to top concept. Second quarter emphasizes implementation and testing. Learn and apply professional communication skills, assess ethics. Students must have completed ME170a; completion of 170b required to earn grade in 170a. Course sequence fulfills ME WIM requirement. Prerequisites: ENGR15, ME80, ME112, ME131, ME123/151. (Cardinal Course certified by the Haas Center).

ME 177. Global Engineers' Education. 3 Units.
A project based course for those who would like to use their engineering backgrounds to address real world challenges faced by underserved communities globally. In direct collaboration with an underserved community from a rural village in India, students will develop engineering solutions to the challenge of sanitation and hygiene. Focus will be on working with the community rather than for them. Concepts covered will include designing with what designers care about at the center, articulating and realizing individual and community aspirations, ethics of engaging with underserved communities, and methodology of working sustainably with an underserved community.

ME 181. Deliverables: A Mechanical Engineering Design Practicum. 3 Units.
This course empowers you with the design process and confidence needed to tackle mechanical design challenges similar to those seen in industry. We will cover valuable design, manufacturing, assembly, and machine design content which you will apply to the weekly projects. These projects are simplified yet representative versions of typical mechanical design challenges seen in industry. You will submit authentic deliverables, such as cad models and technical drawings, and present those deliverables live in a ¿design review¿ format. With frequent feedback, reflection, revision, and repetition, you will refine these professional skills. By successfully completing this course you will bridge the gap between the lessons learned in school and the professional capabilities expected to be an effective engineer in industry. This course will be taught fully online AY21 Autumn Quarter. .

ME 182. Electric Transportation. 3 Units.
Transportation accounts for nearly one-third of American energy use and greenhouse gas emissions and three-quarters of American oil consumption. It has crucial impacts on climate change, air pollution, resource depletion, and national security. Students wishing to address these issues reconsider how we move, finding sustainable transportation solutions. An introduction to the issue, covering the past and present of transportation and its impacts; examining alternative fuel proposals; and digging deeper into the most promising option: battery electric vehicles. Energy requirements of air, ground, and maritime transportation; design of electric motors, power control systems, drive trains, and batteries; and technologies for generating renewable energy. Students will also have a fun opportunity for a hands-on experience with an electric car. Prerequisites: Introduction to calculus and Physics AP or elementary mechanics.

ME 191. Engineering Problems and Experimental Investigation. 1-5 Unit.
Directed study and research for undergraduates on a subject of mutual interest to student and staff member. Student must find faculty sponsor and have approval of adviser.

ME 191H. Honors Research. 1-5 Unit.
Student must find faculty honors adviser and apply for admission to the honors program.nn (Staff).

ME 195A. Food, Design & Technology. 1 Unit.
Food has been a great source of inspiration for many entrepreneurs and designers. In Silicon Valley, the number of food design solutions has increased tremendously. The goal of this course is to expose students to the landscape of food innovation and design. We will look at food in two different lenses--design and technology. In the first half of the course, students will learn the design thinking process through food. In the next half, students will explore various applications of the design thinking methodology in the real world. Students will do so by actively asking questions, participating in discussions, and engaging in hands-on activities led by industry leaders and experts. Weekly readings will be assigned.

ME 199A. Practical Training. 1 Unit.
For undergraduate students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the Student Services Office does not sponsor CPT. Students are allowed only two quarters of CPT per degree program. Course may be repeated twice.

ME 203. Design and Manufacturing. 4 Units.
ME203 is intended for any graduate students who may want the opportunity to design and prototype a project of meaning to them. Undergraduate mechanical engineering and product design students should register for ME103.nnnME 203 will be taught on line through ZOOM and Canvas resources. Depending on evolving COVID-19 regulations, students may enjoy limited access to Product Realization Laboratory structured laboratory activities. The course will be organized in two chapters over 10 weeks. Chapter One, DESIGN, will commence with brainstorming, and conclude with a full product design presentation for the creation of a single unit including CAD models, Bill of Materials, and Operations Sequence. Chapter Two, MANUFACURING will commence with redesign for large scale manufacturing and end with a Manufacturing Design Plan including a Design for Manufacturability, a Bill of Materials, a recommendation for Manufacturing Processes, and a Unit Marginal Manufacturing Cost Estimate.

ME 206A. Design for Extreme Affordability. 4 Units.
Design for Extreme Affordability (fondly called Extreme) is a two-quarter course offered by the d.school through the School of Engineering and the Graduate School of Business. This multidisciplinary project-based experience creates an enabling environment in which students learn to design products and services that will change the lives of the world's poorest citizens. Students work directly with course partners on real world problems, the culmination of which is actual implementation and real impact. Topics include design thinking, product and service design, rapid prototype engineering and testing, business modelling, social entrepreneurship, team dynamics, impact measurement, operations planning and ethics. Possibility to travel overseas during spring break. Previous projects include d.light, Driptech, Earthenable, Embrace, the Lotus Pump, MiracleBrace, Noora Health and Sanku. Periodic design reviews; Final course presentation and expo; industry and adviser interaction. Limited enrollment via application. Must sign up for ME206A and ME206B. See extreme.stanford.edu.

ME 206B. Design for Extreme Affordability. 4 Units.
Design for Extreme Affordability (fondly called Extreme) is a two-quarter course offered by the d.school through the School of Engineering and the Graduate School of Business. This multidisciplinary project-based experience creates an enabling environment in which students learn to design products and services that will change the lives of the world's poorest citizens. Students work directly with course partners on real world problems, the culmination of which is actual implementation and real impact. Topics include design thinking, product and service design, rapid prototype engineering and testing, business modelling, social entrepreneurship, team dynamics, impact measurement, operations planning and ethics. Possibility to travel overseas during spring break. Previous projects include d.light, Driptech, Earthenable, Embrace, the Lotus Pump, MiracleBrace, Noora Health and Sanku. Periodic design reviews; Final course presentation and expo; industry and adviser interaction. Limited enrollment via application. Must sign up for ME206A and ME206B. See extreme.stanford.edu.

ME 207. Movie Design. 2 Units.
Learn the ins and outs of high-speed filmmaking in the digital age; writing, directing, shooting, and editing. We¿ll do it through a rapid prototyping approach to filmmaking. Whether you have tons of experience or none, you¿ll leave with new tactics that will up your storytelling, filmmaking, and design chops simultaneously. These techniques are useful whether you plan to move to Hollywood or create a video for the web.nn Project-based: students will design, write, shoot, edit, and screen a short film in the span of one week. It¿s going to be quick but intense, kind of like cross-fit for your storytelling and video creating muscles. You¿ll sweat a bit, but you¿ll feel confident afterwards. Students should be prepared to spend significant amount of out of class work-time creating movies: for one week + one weekend, see "Notes" for specific dates. Admission by application. See dschool.stanford.edu/classes for more information.

ME 208. Patent Law and Strategy for Innovators and Entrepreneurs. 2-3 Units.
This course teaches the essentials for a startup to build a valuable patent portfolio and avoid a patent infringement lawsuit. Jeffrey Schox, who is the top recommended patent attorney for Y Combinator, built the patent portfolio for Twilio (IPO), Cruise ($1B acquisition), and 300 startups that have collectively raised over $3B in venture capital. This course is equally applicable to EE, CS, and Bioengineering students. For those students who are interested in a career in Patent Law, please note that this course is a prerequisite for ME238 Patent Prosecution.
Same as: MS&E 278

ME 209. Imperfections in Crystalline Solids. 3 Units.
To develop a basic quantitative understanding of the behavior of point, line and planar defects in crystalline solids. Particular attention is focused on those defects that control the thermodynamic, structural and mechanical properties of crystalline materials.

ME 210. Introduction to Mechatronics. 4 Units.
Technologies involved in mechatronics (intelligent electro-mechanical systems), and techniques to apply this technology to mecatronic system design. Topics include: electronics (A/D, D/A converters, op-amps, filters, power devices); software program design, event-driven programming; hardware and DC stepper motors, solenoids, and robust sensing. Large, open-ended team project. Prerequisites: ENGR 40, CS 106, or equivalents.
Same as: EE 118

ME 211. Psychology of Design: Experience and Thinking about Thinking in Design. 2 Units.
In this class, you will go through various design activities with a specific focus on your thinking, perception, and feelings. This will be a ten-week intensive course on practicing and experiencing your (self-)awareness through observing, assessing, documenting, and reflecting on your modes of thinking and related activities in specific environments.The course aims to help you develop your own strategies to be more in control of your thoughts, feelings, motivations, and actions.

ME 215C. Analytical Product Design. 4 Units.
Analytical design experience for consumer product. Integration of models of engineering function, manufacturing costs, and market conditions. Introduction to modeling micro economics, market models, and consumer surveying as applied in product design. Introduction to consumer product cost modeling. Draw from other coursework to build engineering function model. Student teams build and link these models in an optimization framework to maximize profitability. Build prototypes for engineering function and form expression.
Same as: APD

ME 216A. Advanced Product Design: Needfinding. 4 Units.
Human needs that lead to the conceptualization of future products, environments, systems, and services. Field work in public and private settings; appraisal of personal values; readings on social ethnographic issues; and needfinding for a corporate client. Emphasis is on developing the flexible thinking skills that enable the designer to navigate the future. Prerequisites for undergraduates: ME115A, ME115B and ME203, or consent of the instructor. AY21 only, concurrent enrollment in 216B is required for Product Design majors.

ME 216B. Advanced Product Design: Implementation 1. 4 Units.
Team-based capstone project using knowledge, methodology, and skills obtained in the Product Design major. Students implement an original design concept and present it to a professional jury. AY21 only, concurrent enrollment in 216A is required.

ME 216C. Advanced Product Design: Implementation 2. 4 Units.
Implementation II is a continuation of ME216B. Students will complete the development process and make their product 'real in the world' in ways that are appropriate to the type of product being developed. Prerequisite: 216A and ME216B.

ME 216M. Introduction to the Design of Smart Products. 3-4 Units.
This course will focus on the technical mechatronic skills as well as the human factors and interaction design considerations required for the design of smart products and devices. Students will learn techniques for rapid prototyping of smart devices, best practices for physical interaction design, fundamentals of affordances and signifiers, and interaction across networked devices. Students will be introduced to design guidelines for integrating electrical components such as PCBs into mechanical assemblies and consider the physical form of devices, not just as enclosures but also as a central component of the smart product. Prerequisites include: CS106A and E40 highly recommended, or instructor approval.
Same as: CS 377N

ME 218A. Smart Product Design Fundamentals. 4-5 Units.
Lecture/Lab. First in the team design project series on programmable electromechanical systems design. Topics: transistors as switches, basic digital circuits, C language features for embedded software, register level programming, input/output ports and user I/O, hardware abstraction layers, software design, event driven programming, state machines, state charts. Programming of the embedded system is done in C. Students must have a computer (Win10 or OSX) on which they can install the tools used in the classes and a workspace to complete the lab assignments (in case the lab is closed due to COVID). Lab fee. Limited Enrollment, must attend first lecture session. Prerequisite: You should have had a programming course taught in C, C++ or Java and an introductory course in circuit analysis prior to enrolling in ME218a. Loaner test instruments will be provided in the event that the lab is closed due to COVID.

ME 218B. Smart Product Design Applications. 4-5 Units.
Lecture/lab. Second in team design project series on programmable electromechanical systems design. Topics: More microcontroller hardware subsystems: timer systems, PWM, interrupts; analog circuits, operational amplifiers, comparators, signal conditioning, interfacing to sensors, actuator characteristics and interfacing, noise, and power supplies. Lab fee. Limited enrollment. Prerequisite: 218A or passing the smart product design fundamentals proficiency examination.

ME 218C. Smart Product Design Practice. 4-5 Units.
Lecture/lab. Third in the series on programmable electromechanical systems design. Topics: inter-processor communication, communication protocols, system design with multiple microprocessors, architecture and assembly language programming for the PIC microcontroller, controlling the embedded software tool chain, A/D and D/A techniques. Team project. Lab fee. Limited enrollment. Prerequisite: 218B.

ME 218D. Smart Product Design: Projects. 3-4 Units.
Lecture/lab. Industrially sponsored project is the culmination of the Smart Product Design sequence. Student teams take on an industrial project requiring application and extension of knowledge gained in the prior three quarters, including prototyping of a final solution with hardware, software, and professional documentation and presentation. Lectures extend the students' knowledge of electronic and software design, and electronic manufacturing techniques. Topics: chip level design of microprocessor systems, real time operating systems, alternate microprocessor architectures, and PCB layout and fabrication. Prerequisite: 218C.

ME 219. The Magic of Materials and Manufacturing. 3 Units.
ME219 is intended for students who anticipate imagining and creating new products and who are interested in how to make the leap from making one to making many. Through a combination of lectures, weekly factory field trips, and multimedia presentations the class will help students acquire foundational professional experience with materials and materiality, manufacturing processes, and the business systems inside factories. We hope to instill in students a deep and life-long love of materials and manufacturing in order to make great products and tell a good story about each one. This class assumes basic knowledge of materials and manufacturing processes which result from taking ENGR 50, ME203, or equivalent course or life experience.nnnME219 will be taught on-line through Zoom and Canvas resources. There may be limited Product Realization Lab access depending on changing COVID-19 regulations. Regardless, students will each receive a kit consisting of tools and consumer products suitable for product deconstruction.

ME 220. Introduction to Sensors. 4 Units.
Sensors are widely used in scientific research and as an integral part of commercial products and automated systems. The basic principles for sensing displacement, force, pressure, acceleration, temperature, optical radiation, nuclear radiation, and other physical parameters. Performance, cost, and operating requirements of available sensors. Elementary electronic circuits which are typically used with sensors. Lecture demonstration of a representative sensor from each category elucidates operating principles and typical performance. Lab experiments with off-the-shelf devices. Recommended Pre-requisites or equivalent knowledge: Physics 43 electromagnetism, Physics 41 mechanics, Math 53 Taylor series approximation, 2nd order Ordinary Diff Eqns, ENGR40A/Engr40 or ME210, i.e. some exposure to building basic circuits.

ME 225. Scaling Your Vision. 3 Units.
Scaling Your Vision is intended for design and engineering oriented students who anticipate or have an interest in launching products. Where the cousin of this class, ME219, is an overview of fabrication and factory systems, this course explores how to go from vision to reality, and from parts to products. We'll explore the systems that enable us to design and produce high-quality products, at scale, at reasonable prices, including quality systems, supply chains, and different ways of conveying intent to factories. Students will acquire a professional foundation in the business of manufacturing through readings, in-class discussion, and roughly one-a-week team projects.

ME 227. Vehicle Dynamics and Control. 3 Units.
The application of dynamics, kinematics, and control theory to the analysis and design of ground vehicle behavior. Simplified models of ride, handling, and braking, their role in developing intuition, and limitations in engineering design. Suspension design fundamentals. Performance and safety enhancement through automatic control systems. In-car laboratory assignments for model validation and kinesthetic understanding of dynamics. Limited enrollment. Prerequisites: ENGR 105, consent of instructor.

ME 228. The Future of Mechanical Engineering. 1 Unit.
This seminar series provides an overview of current and emerging research topics in mechanical engineering and its application to engineering and scientific problems. The seminar is targeted at senior mechanical engineering undergraduates and mechanical engineering graduate students. Presenters will be selected external speakers who feature exciting and cutting-edge research of mechanical engineering.

ME 231. Educating Young STEM Thinkers. 3-5 Units.
The course introduces students to the design thinking process, the national conversations about the future of STEM careers, and opportunities to work with middle school students and K-12 teachers in STEM-based after-school activities and intercession camps. The course is both theory and practice focused. The purpose is twofold; to provide reflection and mentoring opportunities for students to learn about pathways to STEM careers and to introduce mentoring opportunities with young STEM thinkers.
Same as: EDUC 239, ME 139

ME 232. Additive Manufacturing- From Fundamentals to Applications. 3 Units.
Additive manufacturing (AM) is an emerging technique for direct conversion of 3D computer aided designs into physical objects using a variety of approaches. AM technologies are simple and flexible processes that allow for the creation of very complex and customizable 3D objects in just a few process steps. This lecture gives an overview of available processes and current research in additive manufacturing. Students will get to know how AM can change the way we prototype and manufacture products in the future.

ME 233. Data-driven modeling of COVID-19. 3 Units.
How to design computational tools to understand the dynamics of the COVID-19 pandemic. Emphasis on mathematical epidemiology, infectious disease models, concepts of effective reproduction number and herd immunity, network modeling, outbreak dynamics and outbreak control, Bayesian methods, model calibration and validation, prediction and uncertaintly quantification; Projects on statistic or mechanistic modeling of COVID-19.

ME 234. Introduction to Neuromechanics. 3 Units.
Understanding the role of mechanics in brain development, physiology, and pathology. Mechanics of brain cells: neurons, mechanobiology, mechanotransduction. Mechanics of brain tissue: experimental testing, constitutive modeling, computational modeling. Mechanics of brain development: gyrification, cortical folding, axon elongation, lissencephaly, polymicrogyria. Mechanics of traumatic brain injury: high impact loading, neural injury. Mechanics of brain tumors, brain cancer, tumor growth, altered cytoskeletal mechanics. Mechanics of neurological disorders: autism, dementia, schizophrenia. Mechanics of brain surgery.

ME 235. Biotransport Phenomena. 3 Units.
The efficient transport of energy, mass, and momentum is essential to the normal function of living systems. Changes in these processes often result in pathological conditions. Transport phenomena are also critical to the design of instrumentation and devices for medical applications and biotechnology. The course aims to provide an introduction to the integrated study of transport processes and their biological applications. It covers the fundamental driving forces for transport in biological systems and the biophysics across a range of length scales from molecules, cells, tissues, organs to whole organisms. Topics covered include chemical gradients, electrical interactions, fluid flow and mass transport.
Same as: BIOPHYS 235

ME 236. Tales to Design Cars By. 1-3 Unit.
Students learn to tell personal narratives and prototype connections between popular and historic media using the automobile. Explores the meaning and impact of personal and preserved car histories. Storytelling techniques serve to make sense of car experiences through engineering design principles and social learning, Replay memories, examine engagement and understand user interviews, to design for the mobility experience of the future. This course celebrates car fascination, and leads the student through finding and telling a car story through the REVS photographic archives, ethnographic research, interviews, and diverse individual and collaborative narrative methods-verbal, non-verbal, and film. Methods draw from socio-cognitive psychology design thinking, and fine art; applied to car storytelling. Course culminates in a final story presentation and showcase. Restricted to co-term and graduate students. Class Size limited to 18.

ME 238. Patent Prosecution. 2-3 Units.
The course follows the patent application process through the important stages: inventor interviews, patentability analysis, drafting claims, drafting a specification, filing a patent application, and responding to an office action. The subject matter and practical instruction relevant to each stage are addressed in the context of current rules and case law. The course includes four written assignments: an invention capture, a claim set, a full patent application, and an Office Action response.Pre-requisites: Law 326 (IP.Patents), Law 409 (Intro IP), ME 208, or MS&E 278.

ME 241. Mechanical Behavior of Nanomaterials. 3 Units.
Mechanical behavior of the following nanoscale solids: 2D materials (metal thin films, graphene), 1D materials (nanowires, carbon nanotubes), and 0D materials (metallic nanoparticles, quantum dots). This course will cover elasticity, plasticity and fracture in nanomaterials, defect-scarce nanomaterials, deformation near free surfaces, coupled optoelectronic and mechanical properties (e.g. piezoelectric nanowires, quantum dots), and nanomechanical measurement techniques. Prerequisites: Mechanics of Materials (ME80) or equivalent.
Same as: MATSCI 241

ME 242B. Mechanical Vibrations. 3 Units.
For M.S.-level graduate students. Covers the vibrations of discrete systems and continuous structures. Introduction to the computational dynamics of linear engineering systems. Review of analytical dynamics of discrete systems; undamped and damped vibrations of N-degree-of-freedom systems; continuous systems; approximation of continuous systems by displacement methods; solution methods for the Eigenvalue problem; direct time-integration methods. Prerequisites: AA 242A or equivalent (recommended but not required); basic knowledge of linear algebra and ODEs; no prior knowledge of structural dynamics is assumed.
Same as: AA 242B

ME 243. Designing Emotion: for Reactive Car Interfaces. 1-3 Unit.
Students learn to define emotions as physiology, expression, and private experience using the automobile and shared space. Explores the meaning and impact of personal and user car experience. Reflective, narrative, and socio-cognitive techniques serve to make sense of mobility experiences; replay memories; examine engagement; understand user interviews. This course celebrates car fascination and leads the student through finding and telling the car experience through discussion, ethnographic research, interviews, and diverse individual and collaborative narrative methods-verbal, non-verbal, and in car experiences. Methods draw from socio-cognitive psychology, design thinking, and fine art, and are applied to the car or mobility experience. Course culminates in a final individual narrative presentation and group project demonstration. Class size limited to 18.

ME 244. Mechanotransduction in Cells and Tissues. 3 Units.
Mechanical cues play a critical role in development, normal functioning of cells and tissues, and various diseases. This course will cover what is known about cellular mechanotransduction, or the processes by which living cells sense and respond to physical cues such as physiological forces or mechanical properties of the tissue microenvironment. Experimental techniques and current areas of active investigation will be highlighted. This class is for graduate students only.
Same as: BIOE 283, BIOPHYS 244

ME 246. Demand Modeling for Transportation. 1 Unit.
Predicting human behavior in the future is key to the success of businesses and policies, whether it's predicting how many new products will be sold next year, or how many people will want to cross a bridge next month. This seminar explores key strategies that demand planners use to predict the future, from travel surveys, observational data and interventions. Students will learn basic techniques, considerations when implementing them, and hear from practitioners applying demand modeling in transportation-specific roles.

ME 250. Internal Combustion Engines. 1-5 Unit.
Internal combustion engines including conventional and turbocharged spark ignition, and diesel engines. Lectures: basic engine cycles, engine components, methods of analysis of engine performance, pollutant emissions, and methods of engine testing. Lab involves hands-on experience with engines and test hardware. Limited enrollment. Prerequisites: 140.

ME 257. Gas-Turbine Design Analysis. 3 Units.
This course is concerned with the design analysis of gas-turbine engines. After reviewing essential concepts of thermo- and aerodynamics, we consider a turbofan gas-turbine engine that is representative of a business aircraft. We will first conduct a performance analysis to match the engine design with aircraft performance requirements. This is followed by examining individual engine components, including compressor, combustor, turbines, and nozzles, thereby increase the level of physical description. Aspects of modern engine concepts, environmental impacts, and advanced engine-analysis methods will be discussed. Students will have the opportunity to develop a simulation code to perform a basic design analysis of a turbofan engine. Course Prerequisites: ENGR 30, ME 70, ME 131B, CME 100.
Same as: ME 357

ME 258. Fracture and Fatigue of Materials and Thin Film Structures. 3 Units.
Linear-elastic and elastic-plastic fracture mechanics from a materials science perspective, emphasizing microstructure and the micromechanisms of fracture. Plane strain fracture toughness and resistance curve behavior. Mechanisms of failure associated with cohesion and adhesion in bulk materials, composites, and thin film structures. Fracture mechanics approaches to toughening and subcritical crack-growth processes, with examples and applications involving cyclic fatigue and environmentally assisted subcritical crack growth. Prerequisite: 151/251, 198/208, or equivalent. SCPD offering.
Same as: MATSCI 358

ME 262. Physics of Wind Energy. 3 Units.
Formerly CEE 261. An introduction to the analysis and modeling of wind energy resources and their extraction. Topics include the physical origins of atmospheric winds; vertical profiles of wind speed and turbulence over land and sea; the wind energy spectrum and its modification by natural topography and built environments; theoretical limits on wind energy extraction by wind turbines and wind farms; modeling of wind turbine aerodynamics and wind farm performance. Final project will focus on development of a new wind energy technology concept. Prerequisites: CEE 262A or ME 351A.
Same as: CEE 261B, ENERGY 262

ME 263. The Chair. 4 Units.
Students design and fabricate a highly refined chair. The process is informed and supported by historical reference, anthropometrics, form studies, user testing, material investigations, and workshops in wood steam-bending, plywood forming, metal tube bending, TIG & MIG welding, upholstery & sewing. Due to COVID-19 restrictions during AY20-21, in-person use of the Product Realization Lab may be limited or not permitted. In this case class will consist of asynchronous lectures and online coaching meetings and office hours. Prerequisite: ME203 or consent of instructor. May be repeated for credit.

ME 265. Technology Licensing and Commercialization. 3 Units.
Course focuses on how to bridge the gap between creation and commercialization with new ideas, inventions, and technology (not limited to mechanical engineering). Comprehensive introduction to patents, copyrights, trademarks, and trade secrets. Covers business strategies and legal aspects of determining what can be owned and licensed, how to determine commercial value, and what agreements and other paperwork is necessary. Discussion includes aspects of Contract and Intellectual Property law as well as provisions of license agreements, NDAs, and their negotiation. All materials provided including many sample documents.

ME 267. Ethics and Equity in Transportation Systems. 3 Units.
Transportation is a crucial element of human life. It enables communication with others, provides access to employment / economic opportunity, and transports goods upon which we depend. However, transportation also generates negative impacts: pollution, noise, energy consumption and risk to human life. Because of its enormous capability to affect our lives, transportation is one of the most highly regulated businesses in the world. These regulations are designed to promote social welfare, improve access, and protect vulnerable populations. This course examines the origins and impacts of transportation policy and regulation: who benefits, who bears the cost, and how social and individual objectives are achieved.

ME 268. Robotics, AI and Design of Future Education. 1 Unit.
The seminar will feature guest lectures from industry and academia to discuss the state of the affairs in the field of Robotics, Artificial Intelligence (AI), and how that will impact the future Education. The time of robotics/AI are upon us. Within the next 10 to 20 years, many jobs will be replaced by robots/AI. We will cover hot topics in Robotics, AI, how we prepare students for the rise of Robotics/AI, how we Re-design and Re-invent our education to adapt to the new era.
Same as: EDUC 468

ME 270A. The Changing Energy Landscape in Europe. 3 Units.
Students will learn about the most daunting challenge of our times: Global Climate Change. This course will offer insights at the interface between environmental challenges, environmental policy, economics, and technology in Europe. Not surprisingly, nations differ in their response to the challenge. Recognizing there is no simple and unique answer to the overarching challenge, students will begin to better understand that vested interests may slow down rapid, but inevitable environmental action. Open to senior undergrads and all graduate levels.

ME 277. Graduate Design Research Techniques. 3-4 Units.
Students from different backgrounds work on real-world design challenges. The Design Thinking process with emphasis on: ethnographic techniques, needfinding, framing and concept generation. The Design Thinking process as a lens to explore ways to better understand people and their culture. Cultural differences as a source of design inspiration, with the understanding that design itself is a culturally embedded practice.

ME 281. Biomechanics of Movement. 3 Units.
Experimental techniques to study human and animal movement including motion capture systems, EMG, force plates, medical imaging, and animation. The mechanical properties of muscle and tendon, and quantitative analysis of musculoskeletal geometry. Projects and demonstrations emphasize applications of mechanics in sports, orthopedics, and rehabilitation.
Same as: BIOE 281

ME 283. Introduction to Biomechanics and Mechanobiology. 3 Units.
Introduction to the mechanical analysis of tissues (biomechanics), and how mechanical cues play a role in regulating tissue development, adaptation, regeneration, and aging (mechanobiology). Topics include tissue viscoelasticity, cardiovascular biomechanics, blood rheology, interstitial flow, bone mechanics, muscle contraction and mechanics, and mechanobiology of the musculoskeletal system. Undergraduates should have taken ME70 and ME80, or equivalent courses.

ME 285. Computational Modeling in the Cardiovascular System. 3 Units.
This course introduces computational modeling methods for cardiovascular blood flow and physiology. Topics in this course include analytical and computational methods for solutions of flow in deformable vessels, one-dimensional equations of blood flow, cardiovascular anatomy, lumped parameter models, vascular trees, scaling laws, biomechanics of the circulatory system, and 3D patient specific modeling with finite elements; course will provide an overview of the diagnosis and treatment of adult and congenital cardiovascular diseases and review recent research in the literature in a journal club format. Students will use SimVascular software to do clinically-oriented projects in patient specific blood flow simulations. Pre-requisites: CME102, ME133 and CME192.
Same as: BIOE 285, CME 285

ME 287. Mechanics of Biological Tissues. 4 Units.
Introduction to the mechanical behaviors of biological tissues in health and disease. Overview of experimental approaches to evaluating tissue properties and mathematical constitutive models. Elastic behaviors of hard tissues, nonlinear elastic and viscoelastic models for soft tissues.

ME 296. Survey of Mechanical Engineering. 1 Unit.
Introduces students to a variety of topics relevant for graduate study in mechanical engineering, includng technical topics representing the breadth of the field, modern tools and techniques, future directions in research and development, and the roles of diversity and innovation. Students will work with the instructor to develop an individualized plan to attend relevant seminars, and meet biweekly as a group to present and discuss findings. Attendance and active participation is required for group meetings.

ME 297. Forecasting for Innovators: Exponential Technologies, Tools and Social Transformation. 3 Units.
This class will employ a suite of quantitative and qualitative foresight methods to understand the future of exponential technologies and their impact. This year, we will develop an integrated forecast of the COVID-19 pandemic¿s long-term trajectory, explore its implications and working as teams translate our insights into innovation opportunities. Specifically, students will develop a long-range forecast, learning and applying a variety of methodologies including scenario planning, cross-impact analysis, expert judgement elicitation and design thinking tools.

ME 298. Silversmithing and Design. 3-4 Units.
Skills involved in working with precious metals at a small scale. The course gives equal attention to design and the techniques involved in investment casting. Winter '21 ME298 will be taught as an online-only course, with no in person teaching. However deliverable items will be exchanged at a pickup/drop off location at the PRL at several times during the quarter.

ME 299A. Practical Training. 1 Unit.
For master's students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the Student Services Office does not sponsor CPT. Students are allowed only two quarters of CPT per degree program. Course may be repeated twice.

ME 299B. Practical Training. 1 Unit.
For Ph.D. students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the student services office does not sponsor CPT. Students are allowed only two quarters of CPT per degree program. Course may be repeated twice.

ME 300A. Linear Algebra with Application to Engineering Computations. 3 Units.
Computer based solution of systems of algebraic equations obtained from engineering problems and eigen-system analysis, Gaussian elimination, effect of round-off error, operation counts, banded matrices arising from discretization of differential equations, ill-conditioned matrices, matrix theory, least square solution of unsolvable systems, solution of non-linear algebraic equations, eigenvalues and eigenvectors, similar matrices, unitary and Hermitian matrices, positive definiteness, Cayley-Hamilton theory and function of a matrix and iterative methods. Prerequisite: familiarity with computer programming, and MATH51.
Same as: CME 200

ME 300B. Partial Differential Equations in Engineering. 3 Units.
Geometric interpretation of partial differential equation (PDE) characteristics; solution of first order PDEs and classification of second-order PDEs; self-similarity; separation of variables as applied to parabolic, hyperbolic, and elliptic PDEs; special functions; eigenfunction expansions; the method of characteristics. If time permits, Fourier integrals and transforms, Laplace transforms. Prerequisite: CME 200/ME 300A, equivalent, or consent of instructor.
Same as: CME 204

ME 300C. Introduction to Numerical Methods for Engineering. 3 Units.
Numerical methods from a user's point of view. Lagrange interpolation, splines. Integration: trapezoid, Romberg, Gauss, adaptive quadrature; numerical solution of ordinary differential equations: explicit and implicit methods, multistep methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigenvalue problems; systems of differential equations, stiffness. Emphasis is on analysis of numerical methods for accuracy, stability, and convergence. Introduction to numerical solutions of partial differential equations; Von Neumann stability analysis; alternating direction implicit methods and nonlinear equations. Prerequisites: CME 200/ME 300A, CME 204/ME 300B.
Same as: CME 206

ME 301. LaunchPad:Design and Launch your Product or Service. 4 Units.
This is an intense course in product design and development offered to graduate students only (no exceptions). In just ten weeks, we will apply principles of design thinking to the real-life challenge of imagining, prototyping, testing and iterating, building, pricing, marketing, distributing and selling your product or service. You will work hard on both sides of your brain. You will experience the joy of success and the (passing) pain of failure along the way. This course is an excellent chance to practice design thinking in a demanding, fast-paced, results-oriented group with support from faculty and industry leaders. This course may change your life. We will treat each team and idea as a real start-up, so the work will be intense. If you do not have a passionate and overwhelming urge to start a business or launch a product or service, this class will not be a fit. Refer to this website for up-to-date class and office hours information: https://www.launchpad.stanford.edu/.

ME 302B. The Future of the Automobile- Driver Assistance and Automated Driving. 1 Unit.
This course provides a holistic overview over the field of vehicle automation. The course starts with the history of vehicle automation and then introduces key terminology and taxonomy. Guest lecturers present the legal and policy aspects of vehicle automation both on the federal and state level. Then, the state of the art in vehicle automation is provided. This includes sensor and actuator technology as well as the driver assistance technology in cars today. Finally, the technology currently being developed for future highly and fully automated vehicles is described, including a high-level introduction of the software and algorithms used as well as HMI and system aspects. Students are asking to work in groups on a current topic related to vehicle automation and present their findings in the final two classes in a short presentation.

ME 302C. The Future of the Automobile- Mobility Entrepreneurship. 1 Unit.
The objective of this course is to develop an understanding for the requirements that go into the design of a highly complex yet easy-to-use product, i.e. the automobile. Students will learn about very different interdisciplinary aspects that characterize the automobile and personal mobility. This is part of a multi-quarter seminar series, which build on one another but can be taken independently. This quarter, students will learn from 10 different founders / C-level executives about how they built their mobility startup to change the world of transportation. Previous classes included speakers from Tesla, Lyft, Pearl Auto, Turo, Nauto. In hearing these founder stories, students will get an insight not only into the world of entrepreneurship but also the multidisciplinary nature of the transportation industry. The course consists of 50-minute discussions with founders, with students encouraged to participate and ask questions of the founders. To obtain credit, students must attend 8 out of 10 classes including the first class.

ME 304D. Designing Your Life. 1 Unit.
The course employs a design thinking approach to help fellows develop a point of view about their life and career. The course focuses on an introduction to design thinking, the integration of work and worldview, and practices that support vocation formation. Includes seminar-style discussions, role-playing, short writing assignments, guest speakers, and individual mentoring and coaching. Open to DCI (Distinguished Career Institute) Fellows only. Additional course information at http://www.designingyourlife.org.

ME 306A. Engineering Design Theory in Practice. 3 Units.
What is high performance in design? How could you improve your performance as a designer? Theories and frameworks from research into engineering design and design thinking are translated into action for developing insights into your design behavior and to develop strategies to improve design performance. Focus on performance in four aspects of design thinking: design as social activity, cognitive activity, physical activity and learning activity. Practice of effective team behaviors for concept generation, decision-making, and conflict-handling. Cognitive strategies from design as problem-solving, design as reflection-in-action, and C-K Theory. Prototyping performance improvements through media cascade and boundary object frameworks. Application of Perception-Action framework for improving self-learning in design. Students engage in multiple projects and a lab component.

ME 306B. Engineering-Design Capital-Formation Theory in Practice. 1-3 Unit.
Engineers, Scientists, Entrepreneurs, and Investors tasked with the intentional creation and delivery of new knowledge, products, services, and experiences to large markets need an understanding of the capital formation process. Students will learn frameworks and theories underlying design thinking for capital formation. Four perspectives will be considered ¿ design as cognitive agility, design as social alignment, design as reflective awareness, and design as multiphase flow. Students will practice high performance team behaviors for capital formation, and they will engage in multiple projects to apply theories to practical situations.

ME 308. Carbon Dioxide and Methane Removal, Utilization, and Sequestration. 1 Unit.
This is a seminar on carbon dioxide and methane removal, utilization, and sequestration options, and their role in decarbonizing the global energy system. This course will cover topics including the global carbon balance, utilizing atmospheric carbon in engineered solutions, recycling and sequestering fossil-based carbon, and enhancing natural carbon sinks. The multidisciplinary lectures and discussions will cover elements of technology, economics, policy and social acceptance, and will be led by a series of guest lecturers. Short group project on carbon solutions.
Same as: EARTHSYS 308, ENERGY 308, ENVRES 295, ESS 308

ME 310A. Global Engineering Design Thinking, Innovation, and Entrepreneurship. 4 Units.
The ME310ABC sequence immerses students in a real-world, globally distributed engineering design experience in the spirit of a Silicon Valley start-up teaching them to manage the chaos and ambiguity inherent in professional design .nTeams of 3-4 Stanford graduate students partner with a similar team at an international university to work on industry-funded design challenges to deliver breakthrough innovation prototypes (http://expe.stanford.edu). Designnchallenges are typically at the HUMAN INTERFACE to Robots, AI, Internet of Things, Autonomous vehicles, and Smart Cities. In ME310A you will learn HUMAN-CENTRIC Design-Thinking with the guidance of a teaching team that includesn3 faculty, expert industry coaches, and academic staff. Your team will explore the problem & solutions spaces using strategic-foresight, design thinking, team-dynamics-management, rapid prototyping, and human-centric problem reframing.

ME 310B. Global Engineering Design Thinking, Innovation, and Entrepreneurship. 4 Units.
ME310B builds on the experience of ME310A. You will learn engineering design-creativity focused on RE-EXPLORING the Problem and Solution spaces using strategic-foresight, design thinking, team-dynamics-management, rapid prototyping, and human-centric problem/solution RE-FRAMING. Your will collaborate with academic partners to create and present end-of-quarter deliverables as you continue working towards the final prototype deliverables duennin June (http://expe.stanford.edu). You are expected to take the ME310ABC sequence. You team members will receive the same grade for ABC. Prerequisite: ME310A.

ME 310C. Global Engineering Design Thinking, Innovation, and Entrepreneurship. 4 Units.
ME310C builds on ME310AB . You will learn to apply pre-production manufacturing techniques dedicated to making your ideas real and testing them with real users to demonstrate serious credibility. Collaborate with academic partners to create and present end-of-quarter deliverables. In June, teams present their results to the world at the Stanford Design EXPErience, a celebratory symposium and exposition where industry liaisons, Silicon Valley professionals, and others converge to explore the final product prototypes. You are expected to take the ME310ABCnnsequence. Your team members will receive the same grade for ABC. Prerequisite: ME310B.

ME 311. Leading Design Teams. 3 Units.
This class teaches students how to be an effective design team leader using the construct of a multifunction new product development (NPD) team and conceptually places students as the leader of a NPD team - the Product Manager. Topics include leadership self-awareness, a review of various leadership styles and skills in diagnosing team dynamics. The understanding and motivation of non-design engineering members of an NPD team (i.e., Sales, Marketing, Finance, HR) will be explored. Classroom activity will include interactive discussion of case studies, hands-on practice of skills, simulations, outside speakers and team presentations. Homework will include case study and source material reading, weekly reflection journals and outside research. A summary presentation of a leadership exemplar will serve as the final exam.

ME 312. Communication in Design. 3 Units.
Communication of design information, ideas, and concepts is central to successful design projects. In this course you will learn about various forms of communication and when/how to apply them in the design process. Topics covered include: structuring communication, selecting key points to communicate, communicating technical information to a non-technical audience. Approaches include: videography, presentations, public speaking. Visual approaches: sketching, storyboarding, journey maps, figures and charts. This course does not cover within-team communication.

ME 313. Human Values and Innovation in Design. 3 Units.
Introduction to the philosophy and practice of the Design Impact program. Hands-on design projects are used as vehicles for learning design thinking's tools and methodology. The relationships among technical, human, aesthetic, and business concerns, and drawing, prototyping, and story-telling a will be explored. The focus is on design thinking process and mindsets including: empathy, point of view, ideation, prototyping and testing. For master's students in the Design Impact program only. For a general introduction to design thinking, see ME 377: Design Thinking Studio, taught Autumn and Winter quarters.

ME 315. The Designer in Society. 3 Units.
This class focuses on individuals and their psychological wellbeing. The class delves into how students perceive themselves and their work, and how they might use design thinking to lead a more creative and committed life. As a participant you read parts of a different book each week and then engage in exercises designed to unlock learnings. In addition, there are two self-selected term projects dealing with eliminating a problem from your life and doing something you have never done before. Apply the first day during class. Attendance at the first session is mandatory.

ME 316A. Design Impact Master's Project I. 2-4 Units.
ME316A, also known as the Idea to Impact class is a Fall/Winter class and a two-quarter commitment is required. The class is a deep dive in design thinking that uses student-led projects to teach design process and methods, based on the themes of Empathic Autonomy in Healthcare, and Empowering Power in Energy. Students will learn the methodologies of design thinking by bringing a product, service, or user-experience design to fruition/impact in the real world, through the market, with corporate partners, or as a research project. Students apply to Idea to Impact in the Summer, and teams are formed after interviews and applications are reviewed. Prerequisite: Graduate student standing.

ME 316B. Design Impact Master's Project II. 2-4 Units.
This is a continuation of ME316A, also known as the Idea to Impact class. The class is a deep dive in design thinking that uses student-led projects to teach design process and methods, based on the themes of Empathic Autonomy in Healthcare, and Empowering Power in Energy. Students will learn the methodologies of design thinking by bringing a product, service, or user-experience design to fruition/impact in the real world in the real world, through the market, with corporate partners, or as a research project. Winter quarter concentrates on building a proof of concept of the project. Prerequisite: Graduate student standing.

ME 316C. Design Impact Master's Project III. 2-4 Units.
For graduate Design Impact students, and select students by application, who have completed ME316A & B. Students, under the supervision of the design faculty, spend the quarter documenting their Idea to Impact projects, implementing them in the world with their partners, or writing up their research.

ME 318. Computer-Aided Product Creation. 3-4 Units.
Design course focusing on an integrated suite of computer tools: rapid prototyping, solid modeling, computer-aided machining, and computer numerical control manufacturing. Students choose, design, and manufacture individual products, emphasizing individual design process and computer design tools. Structured lab experiences build a basic CAD/CAM/CNC proficiency. Due to COVID-19 restrictions during AY20-21, in-person use of the Product Realization Lab may be limited or not permitted. In this case class will consist of asynchronous lectures and online coaching meetings and office hours. Limited enrollment. Prerequisite: ME103 or equivalent and consent of instructor. Prerequisite: ME 203 or consent of instructor.

ME 319. Topics in Multi-Limbed Manipulation. 3 Units.
Course covers fundamental topics in manipulation with fingers or locomotion with multiple legs. Starting topics include: mobility, manipulability, contact kinematics, force closure, nonholonomic constraints. We branch into topics based on student interest such as automated grasp choice, quasistatic sliding manipulation, locomotion with friction or adhesion. Students will have one or two readings each week and will meet with instructor to prepare leading the discussion and developing exercises for the next week. Exercises can be numerical or symbolic.

ME 320. Introduction to Robotics. 3 Units.
Robotics foundations in modeling, design, planning, and control. Class covers relevant results from geometry, kinematics, statics, dynamics, motion planning, and control, providing the basic methodologies and tools in robotics research and applications. Concepts and models are illustrated through physical robot platforms, interactive robot simulations, and video segments relevant to historical research developments or to emerging application areas in the field. Recommended: matrix algebra. Same as: CS 223A

ME 321. Optofluidics: Interplay of Light and Fluids at the Micro and Nanoscale. 3 Units.
Many optical systems in biology have sophisticated designs with functions that conventional optics cannot achieve: no synthetic materials, for example, can provide the camouflage capability exhibited by some animals. This course overviews recent efforts--some inspired by examples in biology--in using fluids, soft materials and nanostructures to create new functions in optics. Topics include electrowetting lenses, electronic inks, colloidal photonic crystals, bioinspired optical nanostructures, nanophotonic biosensors, lens-less optofluidic microscopes. The use of optics to control fluids is also discussed: optoelectronic tweezers, particle trapping and transport, microrheology, optofluidic sorters, fabrication and self-assembly of novel micro and nanostructures.

ME 322. Kinematic Synthesis of Mechanisms. 3 Units.
The rational design of linkages. Techniques to determine linkage proportions to fulfill design requirements using analytical, graphical, and computer based methods.

ME 324. Precision Engineering. 4 Units.
ME324 is designed for MS candidates who have an interest in, and some experience with, mechanical design and manufacturing. Advances in engineering are often enabled by increased precision in design and manufacturing. A common misconception is that increased precision can only be achieved through extremely tight tolerances and wildly expensive components. The principles of precision engineering lead to better engineering solutions even when very high accuracy is not involved. We will explore metrology tools, concepts in accuracy, kinematic design, flexures and alignment solutions, geometric dimensioning and tolerancing, materials selection, and optical alignments.nnnME324 will be taught on-line through Zoom and Canvas resources. There will be weekly, recorded presentations, and small group coaching and presentation of work sessions.

ME 325. Making Multiples: Injection Molding. 3 Units.
Design course focusing on the process of injection molding as a prototyping and manufacturing tool. Coursework will include creating and evaluating initial design concepts, detailed part design, mold design, mold manufacturing, molding parts, and testing and evaluating the results. Students will work primarily on individually selected projects, using each project as a tool to continue developing and exercising individual design process. Lectures and field trips will provide students with context for their work in the Stanford Product Realization Lab. Prerequisite: ME318 or consent of instructors.

ME 327. Design and Control of Haptic Systems. 3 Units.
Study of the design and control of haptic systems, which provide touch feedback to human users interacting with virtual environments and teleoperated robots. Focus is on device modeling (kinematics and dynamics), synthesis and analysis of control systems, design and implementation, and human interaction with haptic systems. Coursework includes homework/laboratory assignments and a hands-on project. Directed toward undergraduate and graduate students in engineering and computer science. Prerequisites: dynamic systems, feedback controls, and MATLAB programming.

ME 328. Medical Robotics. 3 Units.
Study of the design and control of robots for medical applications. Focus is on robotics in surgery and interventional radiology, with introduction to other healthcare robots. Delivery is through instructor lectures and weekly guest speakers. Coursework includes homework and laboratory assignments, an exam, and a research-oriented project. Directed toward graduate students and advanced undergraduates in engineering and computer science; no medical background required. Prerequisites: dynamic systems and MATLAB programming. Suggested experience with C/C++ programming, feedback control design, and linear systems. Cannot be taken concurrently with CS 571.

ME 329. Mechanical Analysis in Design. 3 Units.
This project based course will cover the application of engineering analysis methods learned in the Mechanics and Finite Element series to real world problems involving the mechanical analysis of a proposed device or process. Students work in teams, and each team has the goal of solving a problem defined jointly with a sponsoring company or research group. Each team will be mentored by a faculty mentor and a mentor from the sponsoring organization. The students will gain experience in the formation of project teams; interdisciplinary communication skills; intellectual property; and project management. Course has limited enrollment.

ME 330. Advanced Kinematics. 3 Units.
Kinematics from mathematical viewpoints. Introduction to algebraic geometry of point, line, and plane elements. Emphasis is on basic theories which have potential application to mechanical linkages, computational geometry, and robotics.

ME 331A. Advanced Dynamics & Computation. 3 Units.
Newton, Euler, momentum, and road-map methods and computational tools for 3-D force and motion analysis of multibody systems. Power, work, and energy. Numerical solutions (e.g., MATLAB, etc.) of nonlinear algebraic and differential equations governing the static and dynamic behavior of multiple degree of freedom systems.

ME 331B. Advanced Dynamics, Simulation & Control. 3 Units.
Advanced methods and computational tools for the efficient formulation of equations of motion for multibody systems. D'Alembert principle. Power, work, and energy. Kane's and Lagrange's method. Computed torque control. Systems with constraints. Quaternions. Numerical solutions (e.g., MATLAB, etc.) of nonlinear algebraic and differential equations governing the behavior of multiple degree of freedom systems. Team-based computational multi-body lab project (inclusion of feed-forward control optional).

ME 332. Introduction to Computational Mechanics. 3 Units.
Provides an introductory overview of modern computational methods for problems arising primarily in mechanics of solids and is intended for students from various engineering disciplines. The course reviews the basic theory of linear solid mechanics and introduces students to the important concept of variational forms, including the principle of minimum potential energy and the principles of virtual work. Specific model problems that will be considered include deformation of bars, beams and membranes, plates, and problems in plane elasticity (plane stress, plane strain, axisymmetric elasticity). The variational forms of these problems are used as the starting point for developing the finite element method (FEM) and boundary element method (BEM) approaches providing an important connection between mechanics and computational methods.
Same as: CME 232

ME 333. Mechanics - Fundamentals and Variational Methods. 3 Units.
The goal of the class is to introduce the foundations of the calculus of variations and its application to obtaining the equations of motion of mechanical systems, beginning with systems of particles, and progressing towards one-dimensional continuum system, to finish with three-dimensional continuum systems. In particular, the basics of tensor algebra and calculus are introduced, and utilized to obtain the linear elasticity equations. The equations that describe the deformation of reduced-order structural models, such as beams and plates, are obtained through the proper imposition of kinematic constraints on the variational principle.

ME 334. Advanced Dynamics, Controls and System Identification. 3 Units.
Modeling and analysis of dynamical systems. This class will cover reference frames and coordinate systems, kinematics and constraints, mass distribution, virtual work, D'Alembert's principle, Lagrange and Hamiltonian equations of motion. We will then consider select topics in controls including: dynamical system stability, feedback linearization, system observability and controllability, and system identification methods. Students will learn and apply these concepts through homework and projects that involve the simulation of dynamical systems. Prerequisites: ENGR15 or equivalent, Recommended: Linear Algebra (EE 263, Math 113, CME 302 or equivalent), Partial Differential Equations (Math 131P or equivalent). This course will be online only in AY21.

ME 335A. Finite Element Analysis. 3 Units.
Fundamental concepts and techniques of primal finite element methods. Method of weighted residuals, Galerkin's method and variational equations. Linear eliptic boundary value problems in one, two and three space dimensions; applications in structural, solid and fluid mechanics and heat transfer. Properties of standard element families and numerically integrated elements. Implementation of the finite element method using Matlab, assembly of equations, and element routines. Lagrange multiplier and penalty methods for treatment of constraints. The mathematical theory of finite elements.

ME 335B. Finite Element Analysis. 3 Units.
Finite element methods for linear dynamic analysis. Eigenvalue, parabolic, and hyperbolic problems. Mathematical properties of semi-discrete (t-continuous) Galerkin approximations. Modal decomposition and direct spectral truncation techniques. Stability, consistency, convergence, and accuracy of ordinary differential equation solvers. Asymptotic stability, over-shoot, and conservation laws for discrete algorithms. Mass reduction. Applications in heat conduction, structural vibrations, and elastic wave propagation. Computer implementation of finite element methods in linear dynamics. Implicit, explicit, and implicit-explicit algorithms and code architectures.

ME 335C. Finite Element Analysis. 3 Units.
Newton's method for nonlinear problems; convergence, limit points and bifurcation; consistent linearization of nonlinear variational forms by directional derivative; tangent operator and residual vector; variational formulation and finite element discretization of nonlinear boundary value problems (e.g. nonlinear heat equation, nonlinear elasticity); enhancements of Newton's method: line-search techniques, quasi-Newton and arc-length methods.

ME 336. Discontinuous Galerkin Methods for Fluid-Flow Simulations. 3 Units.
This course is designed to provide an introduction to discontinuous Galerkin (DG) methods and related high-order discontinuous solution techniques for solving partial differential equations with application to fluid flows. The course covers mathematical and theoretical concepts of the DG-methods and connections to finite-element and finite-volume methods. Computational aspects on the discretization, stabilization methods, flux-evaluations, and integration techniques will be discussed. Problems and examples will be drawn from advection-reaction-diffusion equations, non-linear Euler and Navier-Stokes systems, and related fluid-dynamics problems. As part of a series of homework assignments and projects, students will develop their own DG-method for solving the compressible flow equations in complex two-dimensional geometries.

ME 337. Mechanics of Growth. 3 Units.
Growth is a distinguishing feature of all living things. This course introduces the concept of living systems through the lens of mechanics. We discuss the basic continuum theory for living systems including the kinematics, balance equations, and constitutive equations and the computational modeling of growth phenomena including growing plants, remodeling bone, healing wounds, growing tumors, atherosclerosis, expanding skin, failing hearts, developing brains, and the effects of high performance training.

ME 338. Continuum Mechanics. 3 Units.
Introduction to vectors and tensors: kinematics, deformation, forces, and stress concept of continua; balance principles; aspects of objectivity; hyperelastic materials; thermodynamics of materials; variational principles. Prerequisite: CEE 291 or equivalent.

ME 339. Introduction to parallel computing using MPI, openMP, and CUDA. 3 Units.
This class will give hands-on experience with programming multicore processors, graphics processing units (GPU), and parallel computers. The focus will be on the message passing interface (MPI, parallel clusters) and the compute unified device architecture (CUDA, GPU). Topics will include multithreaded programs, GPU computing, computer cluster programming, C++ threads, OpenMP, CUDA, and MPI. Pre-requisites include C++, templates, debugging, UNIX, makefile, numerical algorithms (differential equations, linear algebra).
Same as: CME 213

ME 340. Mechanics - Elasticity and Inelasticity. 3 Units.
Introduction to the theories of elasticity, plasticity and fracture and their applications. Elasticity: Definition of stress, strain, and elastic energy; equilibrium and compatibility conditions; and formulation of boundary value problems. Stress function approach to solve 2D elasticity problems and Greenâs function approach in 3D. Applications to contact and crack. Plasticity: Yield surface, associative flow rule, strain hardening models, crystal plasticity models. Applications to plastic bending, torsion and pressure vessels. Fracture: Linear elastic fracture mechanics, J-integral, Dugdale-Barrenblatt crack model. Applications to brittle fracture and fatigue crack growth. Computer programming in Matlab is used to aid analytic derivation and numerical solutions.

ME 341. Design Experiments. 3 Units.
Design experiments to learn about the relationship between users and products, with an emphasis on quantitative output that is tested with statistics. Students will be exposed to all components of the experimental design process: research proposition, literature review, detailed hypotheses, method selection, experimental instruments, subject selection, pilot studies, analysis approaches, reporting results, and discussing conclusions. Students will receive human subjects training and complete the IRB certificate. Possible experiment design tools include in-person observation and interviews, web surveys, and eye-tracking.

ME 341X. Statistics for Design Experiments. 1 Unit.
Feedback from users is fundamental to good design. Often this feedback is collected in the form of a survey, resulting in data requiring both analysis and synthesis. Course content will be delivered via live and on-line video lectures, with group classroom time dedicated to completing the lab assignments. You will learn the specific skills necessary to design, launch and collect data using an online survey tool (Qualtrics), how to analyze the results using R for Statistical Computing, and to create simple graphical representations of statistical data. This course is designed to complement ME341 ¿ Design Experiments although enrollment in ME341 is not a prerequisite for this course. One-unit credit requires completion of an analysis project using data collected as part of this class. Auditors welcome.

ME 342A. Mechanobiology and Biofabrication Methods. 3 Units.
Cell mechanobiology topics including cell structure, mechanical models, and chemo-mechanical signaling. Review and apply methods for controlling and analyzing the biomechanics of cells using traction force microscopy, AFM, micropatterning and cell stimulation. Practice and theory for the design and application of methods for quantitative cell mechanobiology.
Same as: BIOE 342A, BIOPHYS 342A

ME 343. Machine Learning for Computational Engineering.. 3 Units.
Linear and kernel support vector machines, deep learning, deep neural networks, generative adversarial networks, physics-based machine learning, forward and reverse mode automatic differentiation, optimization algorithms for machine learning, TensorFlow, PyTorch.
Same as: CME 216

ME 344. Introduction to High Performance Computing. 3 Units.
ME 344 is an introductory course on High Performance Computing Systems, providing a solid foundation in parallel computer architectures, cluster operating systems, and resource management. This course will discuss fundamentals of what comprises an HPC cluster, and how we can take advantage of such systems to solve large-scale problems in wide ranging applications like computational fluid dynamics, image processing, machine learning and analytics. Students will take advantage of Open HPC, Intel Parallel Studio, Environment Modules, and cloud-based architectures via lectures, live tutorials, and laboratory work on their own HPC Clusters. This year includes building an HPC Cluster via remote installation of physical hardware, configuring and optimizing a high-speed Infiniband network, and an introduction to parallel programming and high performance python. Students will complete the course with a project using their own clusters to interrogate and model a COVID-19 dataset. There are no prerequisites for computer programming languages. Many of the tasks involve scripting languages. Knowledge of bash and python are helpful to get the most out of the course. Group work and collaboration on projects is allowed and encouraged.

ME 344S. HPC-AI Summer Seminar Series. 1 Unit.
How will high performance computing and artificial intelligence change the way you live, work and learn? What skill sets will you need in the future? The HPC-AI Summer Seminar Series, presented by the Stanford High Performance Computing Center and the HPC-AI Advisory Council, combines thought leadership and practical insights with topics of great societal importance and responsibility¿from applications, tools and techniques to delving into emerging trends and technologies. These experts and influencers who are shaping our HPC and AI future will share their vision and will address audience questions. The overarching theme this year is the potential influence and impact of HPC and AI to battle COVID-19. Students of all academic backgrounds and interests are encouraged to register for this 1-unit course. No prerequisites required. Register early.

ME 345. Fatigue Design and Analysis. 3 Units.
The mechanism and occurrences of fatigue of materials. Methods for predicting fatigue life and for protecting against premature fatigue failure. Use of elastic stress and elastic-plastic strain analyses to predict crack initiation life. Use of linear elastic fracture mechanics to predict crack propagation life. Effects of stress concentrations, manufacturing processes, load sequence, irregular loading, multi-axial loading. Subject is treated from the viewpoints of the engineer seeking up-to-date methods of life prediction and the researcher interested in improving understanding of fatigue behavior. Prerequisite: undergraduate mechanics of materials.

ME 346A. Introduction to Statistical Mechanics. 3 Units.
The main purpose of this course is to provide students with enough statistical mechanics background to the Molecular Simulations classes (ME 346B,C), including the fundamental concepts such as ensemble, entropy, and free energy, etc. The main theme of this course is how the laws at the macroscale (thermodynamics) can be obtained by analyzing the spontaneous fluctuations at the microscale (dynamics of molecules). Topics include thermodynamics, probability theory, information entropy, statistical ensembles, phase transition and phase equilibrium. Recommended: PHYSICS 110 or equivalent.

ME 346B. Introduction to Molecular Simulations. 3 Units.
Algorithms of molecular simulations and underlying theories. Molecular dynamics, time integrators, modeling thermodynamic ensembles (NPT, NVT). Monte Carlo simulations. Applications in solids, liquids, polymers, phase transitions, and combination with machine learning tools. Examples provided in easy-to-use Python Notebooks. Final projects.

ME 346C. Advanced Techniques for Molecular Simulations. 3 Units.
Advanced methods for computer simulations of solids and molecules. Methods for long-range force calculation, including Ewald methods and fast multipole method. Methods for free energy calculation, such as thermodynamic integration. Methods for predicting rates of rare events (e.g. nucleation), including nudged elastic band method and umbrella sampling method. Students will work on projects in teams.

ME 347. Waves in Solids and Fluids. 3 Units.
Wave propagation and sources in elastic solids and compressible fluids; body, surface, and interface waves in homogeneous and plane layered media; dispersion, phase and group velocities; reflection and transmission; near-field, far-field, and static limits; effects of gravity, surface and internal gravity waves; Fourier methods and solutions in the time and frequency domains; Green's functions; reciprocity; adjoint methods and full-waveform inversion; point and line sources, finite sources, moving sources and directivity effects; multipole expansions; source representation in solids using transformation strain; application to earthquakes, volcanoes, and tsunamis. Prerequisites: Graduate-level background in continuum mechanics.
Same as: GEOPHYS 238

ME 348. Experimental Stress Analysis. 3 Units.
Theory and applications of photoelasticity, strain sensors, and holographic interferometry. Comparison of test results with theoretical predictions of stress and strain. Discussion of of other methods (optical fiber strain sensors,digital image correlation, thermoelasticity, Moire interferometry, residual stress determination). nnSix labs plus mini-project. Prerequisite: undergraduate mechanics of materials.nnLimited enrollment. In AY21, classes will be online. Labs will be done via online means as well.

ME 351A. Fluid Mechanics. 3 Units.
Exact and approximate analysis of fluid flow covering kinematics, global and differential equations of mass, momentum, and energy conservation. Forces and stresses in fluids. Euler¿s equations and the Bernoulli theorem applied to inviscid flows. Vorticity dynamics. Topics in irrotational flow: stream function and velocity potential for exact and approximate solutions; superposition of solutions; complex potential function; circulation and lift. Some boundary layer concepts.

ME 351B. Fluid Mechanics. 3 Units.
Laminar viscous fluid flow. Governing equations, boundary conditions, and constitutive laws. Exact solutions for parallel flows. Creeping flow limit, lubrication theory, and boundary layer theory including free-shear layers and approximate methods of solution; boundary layer separation. Introduction to stability theory and transition to turbulence, and turbulent boundary layers. Prerequisite: 351A.

ME 352A. Radiative Heat Transfer. 3 Units.
The fundamentals of thermal radiation heat transfer; blackbody radiation laws; radiative properties of non-black surfaces; analysis of radiative exchange between surfaces and in enclosures; combined radiation, conduction, and convection; radiative transfer in absorbing, emitting, and scattering media. Advanced material for students with interests in heat transfer, as applied in high-temperature energy conversion systems. Take 352B,C for depth in heat transfer. Prerequisites: graduate standing and undergraduate course in heat transfer. Recommended: computer skills.

ME 352B. Fundamentals of Heat Conduction. 3 Units.
Physical description of heat conduction in solids, liquids, and gases. The heat diffusion equation and its solution using analytical and numerical techniques. Data and microscopic models for the thermal conductivity of solids, liquids, and gases, and for the thermal resistance at solid-solid and solid-liquid boundaries. Introduction to the kinetic theory of heat transport, focusing on applications for composite materials, semiconductor devices, micromachined sensors and actuators, and rarefied gases. Prerequisite: consent of instructor.

ME 352C. Convective Heat Transfer. 3 Units.
Prediction of heat and mass transfer rates based on analytical and numerical solutions of the governing partial differential equations. Heat transfer in fully developed pipe and channel flow, pipe entrance flow, laminar boundary layers, and turbulent boundary layers. Superposition methods for handling non-uniform wall boundary conditions. Approximate models for turbulent flows. Comparison of exact and approximate analyses to modern experimental results. General introduction to heat transfer in complex flows. Prerequisite: 351A or equivalent.

ME 352D. Nanoscale heat, mass and charge transport. 3 Units.
Fundamentals of heat, mass and charge transport in solids, liquids and gases. Emphasis on the origins of the properties of matter. Translation of scientific understanding to design and predict the behavior of novel engineering devices and systems that span semiconductors, biotechnology, energy and the environment.

ME 354. Experimental Methods in Fluid Mechanics. 4-5 Units.
Experimental methods associated with the interfacing of laboratory instruments, experimental control, sampling strategies, data analysis, and introductory image processing. Instrumentation including point-wise anemometers and particle image tracking systems. Lab. Prerequisites: previous experience with computer programming and consent of instructor. Limited enrollment.

ME 355. Compressible Flow. 3 Units.
Topics include quasi-one-dimensional isentropic flow in variable area ducts, normal shock waves, oblique shock and expansion waves, flow in ducts with friction and heat transfer, unsteady one-dimensional flow, and steady two-dimensional supersonic flow.

ME 356. Hypersonic Aerothermodynamics. 3 Units.
History of hypersonic flight technology. Inviscid hypersonic flows. Rankine-Hugoniot shock-jump relations at high Mach numbers. Newtonian approximation. Small-disturbance equations for hypersonic aerodynamics. Mach-number independence. Hypersonic similarity. Hypersonic boundary layers and viscous interactions. Aerodynamic heating. Self-similar solutions and analogies. Shock-shock interactions and shock-interference heating. Reentry aerothermodynamics. Effects of the entropy layer. Ablation shields. Thermodynamic and chemical nonequilibrium effects in hypersonics. Transition in hypersonic boundary layers. Effects of incident shock waves. Modern computational developments in hypersonics. Engineering applications of hypersonics in aeronautics and astronautics.

ME 357. Gas-Turbine Design Analysis. 3 Units.
This course is concerned with the design analysis of gas-turbine engines. After reviewing essential concepts of thermo- and aerodynamics, we consider a turbofan gas-turbine engine that is representative of a business aircraft. We will first conduct a performance analysis to match the engine design with aircraft performance requirements. This is followed by examining individual engine components, including compressor, combustor, turbines, and nozzles, thereby increase the level of physical description. Aspects of modern engine concepts, environmental impacts, and advanced engine-analysis methods will be discussed. Students will have the opportunity to develop a simulation code to perform a basic design analysis of a turbofan engine. Course Prerequisites: ENGR 30, ME 70, ME 131B, CME 100.
Same as: ME 257

ME 360. Physics of Microfluidics. 3 Units.
Survey of the physics underlying a wide range of microfluidic devices. Course will review basic, simple principles around fluid flow; convective heat and mass transfer; flows of bubbles, drops, and particles; Brownian particles; Taylor dispersion; capillarity; electrokinetics; mixing; jetting; and chemical reactions. Applications of these systems include molecular diagnostics, genetic and proteomic analysis, single-cell analysis, chemical detection, microelectronics cooling, and studies of basic physics and chemistry. We will review recent scientific literature with a goal of deducing simplified explanations, scaling arguments, and back-of-the-envelope approximations of the relevant physics and device performance.

ME 361. Turbulence. 3 Units.
The nature of turbulent flows, statistical and spectral description of turbulence, coherent structures, spatial and temporal scales of turbulent flows. Averaging, two-point correlations and governing equations. Reynolds averaged equations and stresses. Free shear flows, turbulent jet, turbulent kinetic energy and kinetic energy dissipation, and kinetic energy budget. Kolmogorov’s hypothesis and energy spectrum. Wall bounded flows, viscous scales, and law of the wall. Turbulence closure modeling for Reynolds averaged Navier Stokes equations. Direct and large eddy simulation of turbulent flows. Subgrid scale modeling. ME300B recommended.

ME 362A. Physical Gas Dynamics. 3 Units.
Concepts and techniques for description of high-temperature and chemically reacting gases from a molecular point of view. Introductory kinetic theory, chemical thermodynamics, and statistical mechanics as applied to properties of gases and gas mixtures. Transport and thermodynamic properties, law of mass action, and equilibrium chemical composition. Maxwellian and Boltzmann distributions of velocity and molecular energy. Examples and applications from areas of current interest such as combustion and materials processing.

ME 362B. Nonequilibrium Processes in High-Temperature Gases. 3 Units.
Chemical kinetics and energy transfer in high-temperature gases. Collision theory, transition state theory, and unimolecular reaction theory. Prerequisie: 362A or consent of instructor.

ME 362C. Rarefied and Ionized Gases. 3 Units.
Compressible, viscous, rarefied, and ionized gas flow models derived from kinetic theory, quantum mechanics, and statistical mechanics. Equilibrium properties and non-equilibrium processes via collisions and radiation. Monte Carlo collision models for non-equilibrium gas dynamics and partially ionized plasmas. Prerequisite: undergraduate courses in fluid mechanics and thermodynamics, ME 362A recommended but not required.
Same as: AA 205

ME 363. Partially Ionized Plasmas and Gas Discharges. 3 Units.
Introduction to partially ionized gases and the nature of gas discharges. Topics: the fundamentals of plasma physics emphasizing collisional and radiative processes, electron and ion transport, ohmic dissipation, oscillations and waves, interaction of electromagnetic waves with plasmas. Applications: plasma diagnostics, plasma propulsion and materials processing. Prerequisite: 362A or consent of instructor.

ME 364. Optical Diagnostics and Spectroscopy. 3 Units.
The spectroscopy of gases and laser-based diagnostic techniques for measurements of species concentrations, temperature, density, and other flow field properties. Topics: electronic, vibrational, and rotational transitions; spectral lineshapes and broadening mechanisms; absorption, fluorescence, Rayleigh and Raman scattering methods; collisional quenching. Prerequisite: 362A or equivalent.

ME 365. Making Multiples: Sand Casting. 4 Units.
ME 365 is a product realization based course integrating designing and making with a focus on a scaled manufacturing process, sand casting. It's graduates will develop technical knowledge regarding design principles, tooling design and creation, mold making, and process parameters. This goal will be achieved by a sequence of three hands-on design and manufacturing projects, supported by lectures, curricular materials, and structured laboratories, and portfolio generation. Prerequisites: ME203, ME318, OR consent of instructor.

ME 367. Optical Diagnostics and Spectroscopy Laboratory. 4 Units.
Principles, procedures, and instrumentation associated with optical measurements in gases and plasmas. Absorption, fluorescence and emission, and light-scattering methods. Measurements of temperature, species concentration, and molecular properties. Lab. Enrollment limited to 16. Prerequisite: 362A or 364.

ME 368. d.Leadership: Leading Disruptive Innovation. 3-4 Units.
d.Leadership is a course that teaches the coaching and leadership skills needed to drive good design process in groups. d.leaders will work on real projects driving design projects within organizations and gain real world skills as they experiment with their leadership style. Take this course if you are inspired by past design classes and want skills to lead design projects beyond Stanford. Preference given to students who have taken other Design Group or d.school classes. Admission by application. See dschool.stanford.edu/classes for more information.
Same as: MS&E 489

ME 368A. Biodesign Innovation: Needs Finding and Concept Creation. 4 Units.
In this two-quarter course series (BIOE 374A/B, MED 272A/B, ME 368A/B, OIT 384/5), multidisciplinary student teams identify real-world unmet healthcare needs, invent new health technologies to address them, and plan for their implementation into patient care. During the first quarter (winter), students select and characterize an important unmet healthcare problem, validate it through primary interviews and secondary research, and then brainstorm and screen initial technology-based solutions. In the second quarter (spring), teams select a lead solution and move it toward the market through prototyping, technical re-risking, strategies to address healthcare-specific requirements (regulation, reimbursement), and business planning. Final presentations in winter and spring are made to a panel of prominent health technology experts and/or investors. Class sessions include faculty-led instruction and case studies, coaching sessions by industry specialists, expert guest lecturers, and interactive team meetings. Enrollment is by application only, and students are required to participate in both quarters of the course. Visit http://biodesign.stanford.edu/programs/stanford-courses/biodesign-innovation.html to access the application, examples of past projects, and student testimonials. More information about Stanford Biodesign, which has led to the creation of 50 venture-backed healthcare companies and has helped hundreds of student launch health technology careers, can be found at http://biodesign.stanford.edu/.
Same as: BIOE 374A, MED 272A

ME 368B. Biodesign Innovation: Concept Development and Implementation. 4 Units.
In this two-quarter course series (BIOE 374A/B, MED 272A/B, ME 368A/B, OIT 384/5), multidisciplinary student teams identify real-world unmet healthcare needs, invent new health technologies to address them, and plan for their implementation into patient care. During the first quarter (winter), students select and characterize an important unmet healthcare problem, validate it through primary interviews and secondary research, and then brainstorm and screen initial technology-based solutions. In the second quarter (spring), teams select a lead solution and move it toward the market through prototyping, technical re-risking, strategies to address healthcare-specific requirements (regulation, reimbursement), and business planning. Final presentations in winter and spring are made to a panel of prominent health technology experts and/or investors. Class sessions include faculty-led instruction and case studies, coaching sessions by industry specialists, expert guest lecturers, and interactive team meetings. Enrollment is by application only, and students are required to participate in both quarters of the course. Visit http://biodesign.stanford.edu/programs/stanford-courses/biodesign-innovation.html to access the application, examples of past projects, and student testimonials. More information about Stanford Biodesign, which has led to the creation of 50 venture-backed healthcare companies and has helped hundreds of student launch health technology careers, can be found at http://biodesign.stanford.edu/.
Same as: BIOE 374B, MED 272B

ME 370A. Energy Systems I: Thermodynamics. 3 Units.
Thermodynamic analysis of energy systems emphasizing systematic methodology for and application of basic principles to generate quantitative understanding. Exergy, mixtures, reacting systems, phase equilibrium, chemical exergy, and modern computational methods for analysis. Prerequisites: undergraduate engineering thermodynamics and computer skills such as Matlab.

ME 370B. Energy Systems II: Modeling and Advanced Concepts. 4 Units.
Development of quantitative device models for complex energy systems, including fuel cells, reformers, combustion engines, and electrolyzers, using thermodynamic and transport analysis. Student groups work on energy systems to develop conceptual understanding, and high-level, quantitative and refined models. Advanced topics in thermodynamics and special topics associated with devices under study. Prerequisite: 370A.

ME 370C. Energy Systems III: Projects. 3-5 Units.
Refinement and calibration of energy system models generated in ME 370B carrying the models to maturity and completion. Integration of device models into a larger model of energy systems. Prerequisites: 370A,B, consent of instructor.

ME 371. Combustion Fundamentals. 3 Units.
Heat of reaction, adiabatic flame temperature, and chemical composition of products of combustion; kinetics of combustion and pollutant formation reactions; conservation equations for multi-component reacting flows; propagation of laminar premixed flames and detonations. Prerequisite: 362A or 370A, or consent of instructor.

ME 372. Combustion Applications. 3 Units.
The role of chemical and physical processes in combustion; ignition, flammability, and quenching of combustible gas mixtures; premixed turbulent flames; laminar and turbulent diffusion flames; combustion of fuel droplets and sprays. Prerequisite: 371.

ME 373. Nanomaterials Synthesis and Applications for Mechanical Engineers. 3 Units.
This course provides an introduction to both combustion synthesis of functional nanomaterials and nanotechnology. The first part of the course will introduce basic principles, synthesis/fabrication techniques and application of nanoscience and nanotechnology. The second part of the course will discuss combustion synthesis of nanostructures in zero-, one- two- and three- dimensions, their characterization methods, physical and chemical properties, and applications in energy conversion systems.

ME 374. Dynamics and Kinetics of Nanoparticles. 3 Units.
Part 1: Thermodynamics, transport theories and properties, aerosol dynamics and reaction kinetics of nanoparticles in fluids. Nucleation, gas kinetic theory of nanoparticles, the Smoluchowski equation, gas-surface reactions, diffusion, thermophoresis, conservation equations and useful solutions. Part 2: Introduction to soot formation, nanoparticles in reacting flows, particle transport and kinetics in flames, atmospheric heterogenous reactions, and nanocatalysis.

ME 377. Design Thinking Studio. 4 Units.
Design Thinking Studio is an immersive introduction to design thinking. You will engage in the real world with your heart, hands and mind to learn and apply the tools and attitudes of design. The class is project-based and emphasizes adopting new behaviors of work. Fieldwork and collaboration with teammates are required and are a critical component of the class. Application required, see dschool.stanford.edu/classes for more information.

ME 378. Tell, Make, Engage: Action Stories for Entrepreneuring. 1-3 Unit.
Individual storytelling action and reflective observations gives the course an evolving framework of evaluative methods, from engineering design; socio cognitive psychology; and art that are formed and reformed by collaborative development within the class. Stories attached to an idea, a discovery or starting up something new, are considered through iterative narrative work, storytelling as rapid prototyping and small group challenges. This course will use qualitative and quantitative methods for story engagement, assessment, and class determined research projects with practice exercises, artifacts, short papers and presentations. Graduate and Co-Term students from all programs welcome. Class size limited to 21.

ME 380. Current Topics in Exoskeleton and Prosthesis Research. 3 Units.
This discussion-based course introduces graduate students to current topics in prosthetic limb and exoskeleton research. We will review and discuss landmark studies and recent advances using the published literature. Topics include: clinical presentations of persons with disabilities; commercially available devices and their limitations; the design of advanced assistive devices; algorithmic techniques for patient-specific device optimization; state of the art in hardware, sensing and control of assistive devices; and assessment of device efficacy using biomechanical and psychophysical measurements. Students will analyze and discuss the literature and give presentations on research papers. Prerequisites: Graduate standing and permission of the instructor.

ME 381. Orthopaedic Bioengineering. 3 Units.
Engineering approaches applied to the musculoskeletal system in the context of surgical and medical care. Fundamental anatomy and physiology. Material and structural characteristics of hard and soft connective tissues and organ systems, and the role of mechanics in normal development and pathogenesis. Engineering methods used in the evaluation and planning of orthopaedic procedures, surgery, and devices. Open to graduate students and undergraduate seniors.
Same as: BIOE 381

ME 387. Soft Tissue Mechanics. 3 Units.
Structure/function relationships and mechanical properties of soft tissues, including nonlinear elasticity, viscoelasticity, and poroelasticity.

ME 389. Biomechanical Research Symposium. 1 Unit.
Guest speakers present contemporary research on experimental and theoretical aspects of biomechanical engineering and bioengineering. May be repeated for credit.

ME 390A. High Temperature Gasdynamics Laboratory Research Project Seminar. 1 Unit.
Review of work in a particular research program and presentations of other related work.

ME 391. Engineering Problems. 1-10 Unit.
Directed study for graduate engineering students on subjects of mutual interest to student and staff member. May be used to prepare for experimental research during a later quarter under 392. Faculty sponsor required.

ME 392. Experimental Investigation of Engineering Problems. 1-10 Unit.
Graduate engineering students undertake experimental investigation under guidance of staff member. Previous work under 391 may be required to provide background for experimental program. Faculty sponsor required.

ME 395. Seminar in Solid Mechanics. 1 Unit.
Required of Ph.D. candidates in solid mechanics. Guest speakers present research topics related to mechanics theory, computational methods, and applications in science and engineering. May be repeated for credit.

ME 397. Design Research Theory and Methodology Seminar. 1-3 Unit.
What do designers do when they do design? How can their performance be improved? ME 397 is a participatory graduate seminar where students create, examine, discuss, and evaluate aspects of these questions. Topics change each quarter, and include design methodology, innovation, human factors, interaction design (robots, agents, devices, cars), computer mediated work, and policy implications. May be repeated for credit.

ME 398. Ph.D. Research Rotation. 1-4 Unit.
Directed research experience for first-year Mechanical Engineering Ph.D. students with faculty sponsors. The student is responsible for arranging the faculty sponsor and registering under the faculty sponsor's section number. Course may be repeated up to four times in the first year. A different faculty sponsor must be selected each time.

ME 400. Thesis. 2-15 Units.
Investigation of some engineering problems. Required of Engineer degree candidates.
Same as: Engineer Degree

ME 406. Turbulence Physics and Modeling Using Numerical Simulation Data. 2 Units.
Prerequisite: consent of instructor.

ME 408. Spectral Methods in Computational Physics. 3 Units.
Data analysis, spectra and correlations, sampling theorem, nonperiodic data, and windowing; spectral methods for numerical solution of partial differential equations; accuracy and computational cost; fast Fourier transform, Galerkin, collocation, and Tau methods; spectral and pseudospectral methods based on Fourier series and eigenfunctions of singular Sturm-Liouville problems; Chebyshev, Legendre, and Laguerre representations; convergence of eigenfunction expansions; discontinuities and Gibbs phenomenon; aliasing errors and control; efficient implementation of spectral methods; spectral methods for complicated domains; time differencing and numerical stability.
Same as: CME 322

ME 410A. Introductory Foresight and Technological Innovation. 3 Units.
Learn to develop long-range, technology-based innovations (5+ years based on industry). This course offers an intensive, hands-on approach using multiple engineering foresight strategies and tools. Model disruptive opportunities and create far-to-near development plans. Three quarter sequence.

ME 410B. Introductory Foresight and Technological Innovation. 3 Units.
Continuation of ME410A. Students will continue developing their invention, integrate additional engineering foresight, and develop an intrinsic innovation mindset. Ongoing discussion of industry examples and contemporary events demonstrate foresight principals and engineering leadership in action.

ME 410C. Introductory Foresight and Technological Innovation. 3 Units.
Continuation of ME410B. Students will continue developing their invention, integrate additional engineering foresight, and develop an intrinsic innovation mindset. Ongoing discussion of industry examples and contemporary events demonstrate foresight principals and engineering leadership in action.

ME 414. Solid State Physics for Mechanical Engineering Experiments. 3 Units.
Introductory overview of principles of statistical mechanics, quantum mechanics and solid-state physics. Provides graduate Mechanical Engineering students with the understanding needed to work on devices or technologies which rely on solid-state physics. (Alternate years).

ME 420. Applied Electrochemistry at Micro- and Nanoscale. 3 Units.
Applied electrochemistry with a focus on energy conversion and storage. Basic concepts of thermodynamics, electrochemistry, and first principal calculations are presented, of which today's fundamentals of electrochemical energy conversion/storage are built. Conventional as well as advanced Li battery concepts/systems and their applications will be a main subject area. intercalation and conversion cathode and anode material families will be introduced and electrochemical function/challenges for energy storage of these materials will be highlighted. Conventional electrolyte materials such as carbonate based liquid electrolyte system and advanced solid-state material will be a topic in class.

ME 421. European Entrepreneurship and Innovation Thought Leaders Seminar. 1 Unit.
Lessons from real-world experiences and challenges in European startups, corporations, universities, non-profit research institutes and venture finance organizations. Speakers include entrepreneurs, leaders from global technology companies, university researchers, venture capitalists, legal experts, senior policy makers and other guests from selected European countries and regions. Geographic scope encompasses Ireland to Russia, and Scandinavia to the Mediterranean region. Enrollment open to undergraduates and graduates in any school or department at Stanford.

ME 421X. Designing Innovation & Entrepreneurship Ecosystems and Institutions: Europe v Silicon Valley. 3-4 Units.
For centuries, Europe has stood at the heart of Western science, engineering,nnindustry/university traditions and institutions. Today, however, Continental Europennhas become a follower in large swaths of the global tech industry. The goal of thisnncourse is to develop students critical thinking skills and understanding of innovationnnand entrepreneurship ecosystems in Europe and Silicon Valley, and of the broadernnethnographic, social, historical and cultural context in which science, engineering,nnmanufacturing, information technology and design occur. Students learn by activelynnparticipating in discussions, asking questions, through directed projects, and engaging with industry leaders and academic experts. Weekly readings are assigned.

ME 429. COMMERCIAL MEMS DEVICE DESIGN. 3 Units.
This course will provide insight into designing MEMS based devices for use in commercial/consumer and automotive sensor applications. Topics to be covered in this MEMS sensor design course will include electromechanical modeling/simulation, compensation for cross-wafer and wafer-to-wafer fabrication variations in a high volume semiconductor manufacturing facility, design for extreme environments (drop shock, temperature, etc.), and some discussion of the unique challenges with respect to consumer and automotive sensor markets. Student teams will develop a MEMS sensor/transducer design (capacitive 3-axis accelerometer), electro-mechanical system model (Matlab based), fabrication process flow with manufacturing analysis (Excel based) in response to a provided design specification sheet.

ME 451A. Advanced Fluid Mechanics Multiphase Flows. 3 Units.
Single particle and multi-particle fluid flow phenomena, mass, momentum and heat transfer, characteristic time and length scales, non-dimensional groups; collection of dispersed-phase elements: instantaneous and averaged descriptions for multiphase flow, Eulerian-Eulerian and Lagrangian-Eulerian statistical representations, mixture theories; models for drag, heat and mass transfer; dilute to dense two-phase flow, granular flows; computer simulation approaches for multiphase flows, emerging research topics. Prerequisites: graduate level fluid mechanics and engineering mathematics, and undergraduate engineering mechanics and thermodynamics.

ME 451B. Advanced Fluid Mechanics - Flow Instabilities. 3 Units.
Waves in fluids: surface waves, internal waves, inertial and acoustic waves, dispersion and group velocity, wave trains, transport due to waves, propagation in slowly varying medium, wave steepening, solitons and solitary waves, shock waves. Instability of fluid motion: dynamical systems, bifurcations, Kelvin-Helmholtz instability, Rayleigh-Benard convection, energy method, global stability, linear stability of parallel flows, necessary and sufficient conditions for stability, viscosity as a destabilizing factor, convective and absolute instability. Focus is on flow instabilities. Prerequisites: graduate courses in compressible and viscous flow.

ME 451C. Advanced Fluid Mechanics - Compressible Turbulence. 3 Units.
Conservation equations. Thermodynamics of ideal gases. Isentropic flows. Crocco-Vazsonyi¿s equation, creation and destruction of vorticity by compressibility effects. Acoustics and generation of sound by turbulence. Shock waves. Kovasznay's modal decomposition of compressible flow, linear and nonlinear modal interactions, interaction of turbulence with shock waves. Turbulent Mach number. Shocklets. Energetics of compressible turbulence, effects of compressibility on homogeneous turbulence, free-shear flows and turbulent boundary layers. Van Driest transformation, recovery temperature, and shock/boundary layer interaction. Strong Reynolds analogy. Subgrid-scale modeling for compressible turbulence. Hypervelocity flows. Prerequisites: Familiarity with compressible laminar flows (ME 355) and incompressible turbulence (ME 361), or consent of the instructor.

ME 451D. Microhydrodynamics. 3 Units.
Transport phenomena on small-length scales appropriate to applications in microfluidics, complex fluids, and biology. The basic equations of mass, momentum, and energy, derived for incompressible fluids and simplified to the slow-flow limit. Topics: solution techniques utilizing expansions of harmonic and Green's functions; singularity solutions; flows involving rigid particles and fluid droplets; applications to suspensions; lubrication theory for flows in confined geometries; slender body theory; and capillarity and wetting. Prerequisites: 120A,B, 300, or equivalents.
Same as: CHEMENG 310

ME 455. Complex Fluids and Non-Newtonian Flows. 3 Units.
Definition of a complex liquid and microrheology. Division of complex fluids into suspensions, solutions, and melts. Suspensions as colloidal and non-colloidal. Extra stress and relation to the stresslet. Suspension rheology including Brownian and non-Brownian fibers. Microhydrodynamics and the Fokker-Planck equation. Linear viscoelasticity and the weak flow limit. Polymer solutions including single mode (dumbbell) and multimode models. Nonlinear viscoelasticity. Intermolecular effects in nondilute solutions and melts and the concept of reptation. Prerequisites: low Reynolds number hydrodynamics or consent of instructor.
Same as: CHEMENG 462

ME 457. Fluid Flow in Microdevices. 3 Units.
Physico-chemical hydrodynamics. Creeping flow, electric double layers, and electrochemical transport such as Nernst-Planck equation; hydrodynamics of solutions of charged and uncharged particles. Device applications include microsystems that perform capillary electrophoresis, drug dispension, and hybridization assays. Emphasis is on bioanalytical applications where electrophoresis, electro-osmosis, and diffusion are important. Prerequisite: consent of instructor.

ME 458. Advanced Topics in Electrokinetics. 3-5 Units.
Electrokinetic theory and electrokinetic separation assays. Electroneutrality approximation and weak electrolyte electrophoresis theory. Capillary zone electrophoresis, field amplified sample stacking, isoelectric focusing, and isotachophoresis. Introduction to general electrohydrodynamics (EHD) theory including the leaky dielectric concept, the Ohmic model formulation, and electrokinetic flow instabilities. Prerequisite: ME 457.

ME 461. Advanced Topics in Turbulence. 3 Units.
Turbulence phenomenology; statistical description and the equations governing the mean flow; fluctuations and their energetics; turbulence closure problem, two-equation turbulence models, and second moment closures; non-local effect of pressure; rapid distortion analysis and effect of shear and compression on turbulence; effect of body forces on turbulent flows; buoyancy-generated turbulence; suppression of turbulence by stratification; turbulent flows of variable density; effect of rotation on homogeneous turbulence; turbulent flows with strong vortices. Prerequisites: 351B and 361A, or consent of instructor.

ME 463. Advanced Topics in Plasma Science and Engineering. 3 Units.
Research areas such as plasma diagnostics, plasma transport, waves and instabilities, and engineering applications.

ME 469. Computational Methods in Fluid Mechanics. 3 Units.
The last two decades have seen the widespread use of Computational Fluid Dynamics (CFD) for analysis and design of thermal-fluids systems in a wide variety of engineering fields. Numerical methods used in CFD have reached a high degree of sophistication and accuracy. The objective of this course is to introduce ¿classical¿ approaches and algorithms used for the numerical simulations of incompressible flows. In addition, some of the more recent developments are described, in particular as they pertain to unstructured meshes and parallel computers. An in-depth analysis of the procedures required to certify numerical codes and results will conclude the course.
Same as: CME 369

ME 470. Uncertainty Quantification. 3 Units.
Uncertainty is an unavoidable component of engineering practice and decision making. Representing a lack of knowledge, uncertainty stymies our attempts to draw scientific conclusions, and to confidently design engineering solutions. Failing to account for uncertainty can lead to false discoveries, while inaccurate assessment of uncertainties can lead to overbuilt engineering designs. Overcoming these issues requires identifying, quantifying, and managing uncertainties through a combination of technical skills and an appropriate mindset. This class will introduce modern techniques for quantifying and propagating uncertainty and current challenges. Emphasis will be on applying techniques in genuine applications, through assignments, case studies, and student-defined projects. Prerequisite: Basic probability and statistics at the level of CME 106 or equivalent.
Same as: CEE 362A

ME 471. Turbulent Combustion. 3 Units.
Basis of turbulent combustion models. Assumption of scale separation between turbulence and combustion, resulting in Reynolds number independence of combustion models. Level-set approach for premixed combustion. Different regimes of premixed turbulent combustion with either kinematic or diffusive flow/chemistry interaction leading to different scaling laws and unified expression for turbulent velocity in both regimes. Models for non-premixed turbulent combustion based on mixture fraction concept. Analytical predictions for flame length of turbulent jets and NOx formation. Partially premixed combustion. Analytical scaling for lift-off heights of lifted diffusion.

ME 485. Modeling and Simulation of Human Movement. 3 Units.
Direct experience with the computational tools used to create simulations of human movement. Lecture/labs on animation of movement; kinematic models of joints; forward dynamic simulation; computational models of muscles, tendons, and ligaments; creation of models from medical images; control of dynamic simulations; collision detection and contact models. Prerequisite: 281, 331A,B, or equivalent.
Same as: BIOE 485

ME 491. Ph.D. Teaching Experience. 3 Units.
Required of Ph.D. students. May be repeated for credit.

ME 492. Mechanical Engineering Teaching Assistance Training. 1 Unit.
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ME 500. Thesis. 1-15 Unit.
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Same as: Ph.D.

ME 571. Surgical Robotics Seminar. 1 Unit.
Surgical robots developed and implemented clinically on varying scales. Seminar goal is to expose students from engineering, medicine, and business to guest lecturers from academia and industry. Engineering and clinical aspects connected to design and use of surgical robots, varying in degree of complexity and procedural role. May be repeated for credit.
Same as: CS 571

ME 801. TGR Project. 0 Units.
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ME 802. TGR Dissertation. 0 Units.
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