UNDERGRADUATE STUDENT MANUAL

Department of Mechanical Engineering and Applied Mechanics

University of Pennsylvania

August 2018

www.me.upenn.edu

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WHAT IS MECHANICAL ENGINEERING AND APPLIED MECHANICS?

Studying Mechanical Engineering and Applied Mechanics teaches you how to analyze, design, and manufacture components, machines, and systems that can withstand force, deformation, heat, and motion while accomplishing a wide variety of useful functions for humanity.

The Department

The Department of Mechanical Engineering and Applied Mechanics (MEAM) was the second engineering curriculum established at the University of Pennsylvania (circa 1872). Our many alumni are noted for their distinguished careers and contributions in engineering, management, science, and education.

Careers in Mechanical Engineering and Applied Mechanics

The MEAM curriculum at Penn offers students a broad-based education that will allow them to adapt to technological developments in a rapidly changing society. At the same time, the curriculum offers the flexibility to specialize in one or more areas of mechanical engineering such as energy engineering, mechanical design, fluid mechanics, or structural mechanics, as well as cross-disciplinary areas such as robotics, biomechanics, micro-electromechanical systems (MEMS), nanotechnology, and mechanics of materials. Our students are encouraged to do research during their course of study and are provided every opportunity to master critical skills that will enable success in their future careers.

The career opportunities available to our graduates are perhaps the broadest among all fields of engineering. Many industries are keen to recruit mechanical engineers, including aerospace, automotive, robotics, electronics, computers, chemical, and biomedical. Positions range from design and manufacturing to research and development to field engineering and testing. While the majority of our graduates pursue engineering careers in industry, some take positions with consulting and financial institutions, and others go on to graduate studies in business, law, and medicine. Given their passion for the subject, a large number of our students choose to pursue a master’s degree in mechanical engineering or a related field at some point in their career.

ADVISING AND DEGREE INFORMATION

Undergraduate Advisor

Each MEAM student is assigned a faculty advisor. This faculty member will work with the student to select courses and will need to approve administrative actions such as course enrollment and petitions. The advisor will also serve as a resource on academic, career, and other issues that may arise. Every effort will be made to maintain continuity from year to year, but advisors may need to be changed in some circumstances. Similarly, students are always free to change to any advisor who will accept them. Students will need to consult with their advisor during the pre-registration period each semester, to plan courses for the following semester.

Students experiencing academic difficulties should meet with their advisor as soon as possible to obtain guidance. When needed, all students are also encouraged to seek help from the MEAM Associate Chair for Undergraduate Affairs (Professor Paulo E. Arratia, parratia@seas.upenn.edu, Towne 271) and the MEAM Undergraduate Coordinator (Lauren Kemp, laurem@seas.upenn.edu, Towne 229).

Mail Folders

Every student in the School of Engineering and Applied Science has a personal mail folder, which is used for distributing announcements and returning graded assignments. Undergraduate mail folders for the MEAM Department are located on the second floor of the Towne Building, across from lab 216. Students should check their mail folder on a regular basis.

Submatriculation

Undergraduate students may begin an engineering graduate program while still completing their undergraduate program. Application is normally made before the end of the student's junior year. The submatriculant may take up to three graduate courses to fulfill both undergraduate and graduate degree requirements while registered as an undergraduate student. To apply for submatriculation, submit an Application for Submatriculation. A minimum GPA of 3.0 is required in order to apply.

Minor in MEAM

Non-major students can earn a minor in Mechanical Engineering and Applied Mechanics by completing at least six approved course units with a grade of C or better. Courses taken on a pass/fail basis do not count toward the MEAM minor. The approved courses include all courses with the prefix MEAM except MEAM 445 and 446 (Senior Design). At most two course units may be at the 100 level (i.e., MEAM 1XX). Up to two cognate courses can be substituted for MEAM courses. Please see the departmental website for an up-to-date listing of cognate courses:
http://www.me.upenn.edu/prospective-students/undergraduates/majors-minors.php#minor

STUDENT ORGANIZATIONS

Student engineering societies are a strong force in shaping professional attitudes and providing information about the profession and job directions. Student organizations also provide opportunities for meeting practicing engineers and for socializing with people of similar professional interests.

The School of Engineering and Applied Science maintains an online list of active student organizations: https://ras.seas.upenn.edu/student-clubs-organizations/

At the time of printing, the listed groups included the following:

- Engineering Student Activities Council (ESAC)
- Engineering Dean's Advisory Board (EDAB)
- Underrepresented Student Advisory Board for Engineers
- Access Engineering
- Alpha Omega Epsilon (AOE)
- American Society of Mechanical Engineers (ASME)
- American Institute of Chemical Engineers (AIChE)
- Biomedical Engineering Society (BMES)
- CommuniTech
- Dining Philosophers
- Engineers in Medicine (eMED)
- Engineers Without Borders, Penn Chapter (PennEWB)
- Hexagon
- Institute of Electrical and Electronics Engineers (IEEE)
- Management and Technology Club (M&T Club)
- Materials Science and Engineering Society
- National Society of Black Engineers (NSBE)
- oSTEM
- Penn ACM SIGGRAPH
- Penn Aerospace Club
- Penn Electric Racing (PER)
- Society of Asian Scientists and Engineers (SASE)
- Society of Hispanic Professional Engineers (SHPE)
- Society of Women Engineers (SWE)
- Tau Beta Pi (TBP)
- Technology Entrepreneurship Club (TEC)
- Theta Tau
- Women in Computer Science (WICS).

Below are brief descriptions of the student organizations that are most closely related to MEAM.

ASME Student Chapter
www.seas.upenn.edu/~asme/
Penn's American Society of Mechanical Engineers (ASME) chapter is a student-run technical and professional society. Students elect their own officers and coordinate a variety of academic, professional, and social activities.
President: Allie Grey, agrey@seas.upenn.edu
Faculty Advisor: Prof. Paulo Arratia, parratia@seas.upenn.edu

National Society of Black Engineers
www.dolphin.upenn.edu/nsbe/
The mission of NSBE is to increase the number of culturally responsible Black Engineers who excel academically, succeed professionally and positively impact the community.
President: Rachel Wilson, upennnsbepresident@gmail.com
Advisor: Dr. Laura Stubbs, lstubbs@seas.upenn.edu

oSTEM
http://www.vpul.upenn.edu/lgbtc/studentgroups
oSTEM at Penn is a chapter of Out in Science, Technology, Engineering & Mathematics (oSTEM), the national student society dedicated to increasing participation of people who identify with lesbian, gay, bisexual, transgender, queer, or ally (LGBTQA) communities in disciplines related to science, technology, engineering, or mathematics (STEM).
ostematpenn@gmail.com

Penn Electric Racing
www.pennelectricracing.com
Penn Electric Racing (PER) designs the nation's top electric race cars to compete at Formula SAE Lincoln. In the past four years, PER has challenged a wide breadth of competitors and has emerged with a first place victory twice, with vehicles that reach a 0-60 time of just 2.6s. Each year, student engineers learn and develop the entire car, building complex power electronics circuitry, custom aerodynamics packages, precision CAD and machining, and far more. Mechanical, Electrical, and Software Engineers are especially needed and all disciplines of engineering and business are welcome. PER's 2019 goal is to win the FSAE Electric Championship again, and push the boundaries of what an electric vehicle can do with a perfected 4WD design.
Operations Leads: Sina Golkari, sgolkari@seas.upenn.edu and Connor Sendel, sendel@seas.upenn.edu
Mechanical Leads: Matt Mendivil, mmendi@seas.upenn.edu and Liam Cook, liamcook@seas.upenn.edu
Electrical Lead: Johnathan Chen, jdchen@seas.upenn.edu
Software Lead: Jay Fleischer, jayf@seas.upenn.edu
Faculty Advisor: Prof. Andrew Jackson, andjac@seas.upenn.edu

The Society of Hispanic Professional Engineers
www.seas.upenn.edu/~shpe/
SHPE promotes the development of Hispanics in engineering, science and other technical professions to achieve educational excellence, economic opportunity and social equity.

President: Alexandra Marcus, shpe@seas.upenn.edu
Faculty Advisors: Prof. Jorge Santiago, santiago@seas.upenn.edu and Prof. Paulo Arratia, parratia@seas.upenn.edu

The Society of Women Engineers
fling.seas.upenn.edu/~swe/cgi-bin/
The mission of SWE is to stimulate women to achieve full potential in careers as engineers and leaders, to expand the image of the engineering profession as a positive force in improving the quality of life and to demonstrate the value of diversity.

President: Emma Dong, emmadong@seas.upenn.edu
Email: pennswe@gmail.com
Faculty Advisor: Prof. Danielle Bassett, dsb@seas.upenn.edu

CURRICULUM IN MECHANICAL ENGINEERING AND APPLIED MECHANICS

Mechanical engineering students are expected to formulate a degree program that is well grounded in the fundamentals while having the breadth that is necessary in today's technology-intensive workplace. Our curriculum allows the student to pursue a number of elective options in depth, either in traditional mechanical engineering subjects or in one or more multidisciplinary engineering programs at Penn. Flexibility in the curriculum, primarily in the junior and senior years, enables the student to study fields such as aeronautics, robotics, design, manufacturing, mechatronics, business administration, advanced mathematics, control systems, and mechanics of materials.

To earn a Bachelor of Science in Engineering (B.S.E.) in MEAM, a student must complete at least 40 course units distributed among six categories, as listed below:

10 credit units = Math and Natural Science courses

10 credit units = Core MEAM courses

10 credit units = Professional Electives

7 credit units = General Electives

\+ 3 credit units = Free Electives

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40 credit units = Total

MEAM students must follow all of the rules and regulations described in the **Penn Engineering Undergraduate Student Handbook**: https://ugrad.seas.upenn.edu/student-handbook/

COURSE PLANNING GUIDE

The following page contains the Course Planning Guide (CPG), which indicates which courses are required and which are recommended in each of the above categories. The CPG also includes websites that provide further information on important topics such as the writing requirement.

The CPG can also be found online:

- MEAM website: www.me.upenn.edu/current-students/undergraduates/degree-requirements.php
- Penn InTouch: https://medley.isc-seo.upenn.edu/penn_portal/intouch/splash.html

AP, IB, PRE-COLLEGE, AND TRANSFER CREDIT

Many MEAM requirements can be satisfied by AP, IB, and Pre-College credit, following these rules: https://admissions.upenn.edu/admissions-and-financial-aid/preparing-for-admission/freshman-admission/external-exam-credit

Students who go abroad will need to plan carefully, as many required MEAM classes are offered only once per year. Students should aim to satisfy some requirements using equivalent classes taken abroad. Here are the rules: https://ugrad.seas.upenn.edu/student-handbook/undergraduate-policies/courses-at-other-institutions/

MEAM COURSE PLANNING GUIDE

Math and Natural Science (10 CU)

www.seas.upenn.edu/undergraduate/handbook/courses/**math-courses**.php

www.seas.upenn.edu/undergraduate/handbook/courses/**nat-science-courses**.php

- ❒ **MATH 104 Calculus I** (Section 6 is recommended)
- ❒ **MATH 114 Calculus II**
- ❒ **MATH 240 Calculus III**
- ❒ **ENM 251 or MATH 241 Calculus IV**
- ❒ **Mathematics elective**[1]
- ❒ **MEAM 110 Intro to Mechanics** [2]
- ❒ **MEAM 147 Intro to Mechanics Lab** [2]
- ❒ **PHYS 151 Principles of Physics II**
- ❒ **CHEM 101 Chemistry I** (Section 4, 5 or EAS 091)
- ❒ **CHEM 053 Chemistry Lab I**
- ❒ **Math or Natural Science** [3]

1. We recommend MATH 312.
2. PHYS 150 is also acceptable.
3. For example: PHYS 364 (Laboratory Electronics).

Core MEAM (10 CU)

- ❒ **MEAM 203 Thermodynamics I**
- ❒ **MEAM 210 Statics & Strength of Materials**
- ❒ **MEAM 211 Eng. Mechanics: Dynamics**
- ❒ **MEAM 247 ME Lab I**
- ❒ **MEAM 248 ME Lab I**
- ❒ **MEAM 302 Fluid Mechanics**
- ❒ **MEAM 321 Vibrations of Mechanical Sys.**
- ❒ **MEAM 333 Heat & Mass Transfer**
- ❒ **MEAM 347 ME Design Lab**
- ❒ **MEAM 348 ME Design Lab**
- ❒ **MEAM 354 Mechanics of Solids**

Note:
Bold courses are required MEAM courses.

Professional Electives (10 CU) [4]

- ❒ **MEAM 445 Design Project I**
- ❒ **MEAM 446 Design Project II**
- ❒ ENGR 105 Intro to Scientific Computing [5]
- ❒ MEAM Upper level______________ [6]
- ❒ MEAM Upper level______________ [6]
- ❒ MEAM Upper level______________ [6]
- ❒ Professional Elective_____________ [7]
- ❒ Professional Elective_____________ [7]
- ❒ Professional Elective_____________ [7, 8]
- ❒ Professional Elective_____________ [7, 8]

4. Maximum of three 100-level courses.
5. CIS 110 and CIS 120 are also acceptable.
6. Choose from MEAM 405, 455, and all MEAM 500-level courses. Neither MEAM 415 nor MEAM 599 may count as upper level.
7. Math, Natural Science, or Engineering categories. We strongly recommend MEAM 101 and MEAM/MSE 220.
8. Advanced dual-degree requirements with approval.

General Electives (7 CU) [9, 10]

www.seas.upenn.edu/undergraduate/handbook/courses/**ssh-breadth**.php

www.seas.upenn.edu/undergraduate/handbook/courses/**tech-bus-courses**.php

- ❒ **EAS 203 Eng. Ethics**
- ❒ H ___________
- ❒ SS ___________
- ❒ H ____________
- ❒ SS or H__________
- ❒ SS, H or TBS ________
- ❒ SS, H or TBS ____________

9. Two of these electives must be taken in the same department to fulfill the **Depth Requirement**: www.seas.upenn.edu/undergraduate/handbook/courses/**ssh-depth**.php

10. One of these electives must fulfill the **Writing Requirement**: www.seas.upenn.edu/undergraduate/handbook/courses/**writing-requirement**.php

Free Electives (3 CU)

www.seas.upenn.edu/undergraduate/handbook/courses/**free-elective**.php

- ❒ ________________________
- ❒ ________________________
- ❒ ________________________

MEAM B.S.E. SAMPLE FOUR-YEAR COURSE PLAN

Many courses have prerequisites, and therefore the sequence in which courses are taken may be important. The following sample course plan shows one sequence that satisfies the prerequisites for the specified courses. However, given the range of individual situations, each student must develop a complete course plan in consultation with his or her academic advisor.

Freshman Year

CUs	FALL		CUs	SPRING	
1.5	**MEAM 110/147**	Intro to Mechanics & Lab	1.5	**PHYS 151**	Principles of Physics II & Lab
1	**MATH 104-006**	Calculus I	1	**MATH 114-002**	Calculus II
1.5	**CHEM 101/053**	Intro to Chemistry & Lab	1	Professional elective (e.g., MEAM 101, MEAM 220)	
1	Elective: Social Science/Humanities		1	Writing Requirement	
Note:	**Students with AP credit for MEAM 110 may take ENGR 105, MEAM 101, and/or MEAM 220. Students with AP credit for MATH 104 should take MATH 114.**		1	Natural Science elective	

Sophomore Year

CUs	FALL		CUs	SPRING	
1	**MEAM 210**	Statics & Strength of Mat'ls	1	**MEAM 203**	Thermodynamics I
0.5	**MEAM 247**	MEAM Laboratory I	1	**MEAM 211**	Engineering Mechanics: Dynamics
1	**MATH 240**	Calculus III	0.5	**MEAM 248**	MEAM Laboratory I
1	**EAS 203**	Engineering Ethics	1	**ENM 251 or MATH 241**	Analytical Methods for Eng. or Calculus IV
1	ENGR 105 or another programming course		1	Social Science/Humanities elective	
1	Professional elective				

Junior Year

CUs	FALL		CUs	SPRING	
1	**MEAM 302**	Fluid Mechanics	1	**MEAM 321**	Vibrations of Mech. Systems
1	**MEAM 354**	Mechanics of Solids	1	**MEAM 333**	Heat & Mass Transfer
1	**MEAM 347**	Mechanical Engineering Design Lab	1	**MEAM 348**	Mechanical Engineering Design Lab
1	Social Science/Humanities elective		1	Math elective	
1	Upper-level MEAM course		1	Free elective	

Senior Year

CUs	FALL		CUs	SPRING	
1	**MEAM 445**	Mechanical Engineering Design Projects	1	**MEAM 446**	Mechanical Engineering Design Projects
1	Upper-level MEAM course		1	Upper-level MEAM course	
1	Professional elective		1	Professional elective	
1	Social Science/Humanities/TBS elective		1	Social Science/Humanities/TBS elective	
1	Free elective		1	Free elective	

Note: **Bold courses** are required MEAM courses.

MEAM ELECTIVE SCHEDULE

http://www.me.upenn.edu/current-students/undergraduates/elective-schedule.php

Fall 2018 Electives

MEAM 101	Intro to Mechanical Design
MEAM 201	Machine Design and Manufacturing
MEAM/MSE 220	Introduction to Materials Science and Engineering
MEAM 415, IPD 515, OIDD 415	Product Design
MEAM/ESE 421	Control for Autonomous Robots
MEAM 502	Energy Engineering in Power Plants & Transportation Systems
MEAM 503	Direct Energy Conversion
MEAM 504	Tribology
MEAM 507/MSE 507	Fundamentals of Materials
MEAM 510	Design of Mechatronic Systems
MEAM 519	Elasticity & Micromechanics of Materials
MEAM 520	Intro to Robotics
MEAM 527	Finite Element Analysis
MEAM 535	Advanced Dynamics
MEAM 543	Performance and Design of Unmanned Aerial Vehicles (UAVs)
MEAM 555, CBE 555, BE 555	Nanoscale Systems Biology
MEAM 570	Transport Process I
MEAM 575	Micro and Nano Fluidics
ENGR 105	Intro to Scientific Computing
ENGR 250	Energy Systems, Resources and Technology
ENM 360	Introduction to Data-driven Modeling
EAS 401/EAS 501	Energy and Its Impacts **fulfills TBS or free elective only*
EAS 545, IPD 545	Engineering Entrepreneurship I **fulfills TBS or free elective only*
EAS 546	Engineering Entrepreneurship II **fulfills TBS or free elective only*

Tentative Spring 2019 Electives

MEAM 101	Introduction to Mechanical Design
MEAM 201	Machine Design and Manufacturing
MEAM 405/505, MSE 405/505	Mechanical Properties of Macro/Nanoscale Materials
MEAM 415, IPD 515, OIDD 415	Product Design
MEAM 508	Materials for Manufacturing
MEAM 513/ESE 505	Feedback Control Design and Analysis
MEAM 514, IPD 514	Design for Manufacturability
MEAM 516	Advanced Mechatronic Reactive Spaces
MEAM 530	Continuum Mechanics
MEAM 536	Viscous Fluid Flow
MEAM 545	Aerodynamics
MEAM 620	Advanced Robotics
ENGR 105	Introduction to Scientific Computing
ENGR 503	Engineering in Oil and Gas
EAS 545, IPD 545	Engineering Entrepreneurship I **fulfills TBS or free elective only*
EAS 546	Engineering Entrepreneurship II **fulfills TBS or free elective only*

RECOMMENDED ELECTIVES OUTSIDE OF MEAM

BIOL 101	Introduction to Biology
BIOL 121	Introduction to Biology - The Molecular Biology of Life
BE 514, IPD 504	Rehabilitation Engineering and Design
CBE 150	Intro to Biotechnology
CIS 160	Mathematical Foundations of Computer Science
CIS 419	Intro to Machine Learning
CIS 421	Artificial Intelligence
ESE 210	Intro to Dynamic Systems
ESE 215	Electrical Circuits and Systems (1.5 CU, with lab)
ESE 150	Digital Audio Basics
ESE 301	Engineering Probability
ESE 305	Foundations of Data Science
GEOL 204	Global Climate Change
GEOL 318	Glaciers Ice and Climate
MATH 312	Linear Algebra
MSE 221	Quantum Physics of Materials
PHYS 230	Thermal Physics and Waves
PHYS 280, BCHE 280	Physical Models of Biological Systems
PHYS 364	Laboratory Electronics
PHYS 411	Intro to Quantum Mechanics

AREAS OF SPECIALIZATION IN MECHANICAL ENGINEERING AND APPLIED MECHANICS

A student interested in pursuing certain engineering disciplines in depth should consider choosing his or her electives accordingly. Students are encouraged to specialize by taking courses in one or two of the areas listed below:

Energy Engineering

MEAM 502	Energy Engineering in Power Plants&Transportation Systems
MEAM 503	Direct Energy Conversion
MEAM 570	Transport
MEAM 572	Micro/Nanoscale Energy Transport
ENGR 250	Energy Systems, Resources & Technology
ENGR 503	Engineering in Oil and Gas
EAS 401/501	Energy and Its Impacts
EAS 402/502	Renewable Energy and Its Impacts

Fluid Mechanics and Aerodynamics

MEAM 527	Finite Elements and Applications
MEAM 513, ESE 505	Feedback Control Design and Analysis
MEAM 530	Continuum Mechanics
MEAM 536	Viscous Fluid Flow and Modern Applications
MEAM 538	Turbulence
MEAM 543	Performance and Design of Unmanned Aerial Vehicles
MEAM 545	Aerodynamics
MEAM 570	Transport

Manufacturing

MEAM 101* — Introduction to Mechanical Design

**Please note: SEAS seniors are not permitted to register for this course. We encourage students to take this course early in their academic careers.*

MEAM 201 — Machine Design and Manufacturing

MEAM 415, IPD 515, OIDD 415/515** — Product Design

***Please note: this course does not count as a MEAM upper level.*

MEAM 508	Materials for Manufacturing
MEAM 510	Design of Mechatronic Systems
MEAM 520	Introduction to Robotics
MEAM 527	Finite Element and Applications
MEAM 550	Design of Microelectromechanical Systems
MEAM 564	Principles of Microfabrication Technology
ESE 215	Electrical Circuits and Systems

Mechatronics and Robotics

MEAM 101* — Introduction to Mechanical Design

Please note: SEAS seniors are not permitted to register for this course. We encourage students to take this course early in their academic careers.

MEAM 510	Design of Mechatronic Systems
MEAM 513, ESE 505	Feedback Control Design and Analysis
MEAM 520	Introduction to Robotics
MEAM 543	Performance and Design of Unmanned Aerial Vehicles

MEAM 620	Advanced Robotics
CIS 120	Introduction to Programming
CIS 581	Computer Vision and Computational Photography
ESE 215	Electrical Circuits and Systems
ESE 350	Embedded Systems/Microcontroller Laboratory

Product Design and Innovation

MEAM 101*	Introduction to Computer Aided Design and Manufacturing

**Please note: SEAS seniors are not permitted to register for this course. We encourage students to take this course early in their academic careers.*

MEAM 201	Machine Design and Manufacturing
MEAM 508	Materials for Manufacturing
MEAM 510	Design of Mechatronic Systems
MEAM 415, IPD 515, OIDD 415/515**	Product Design

***Please note: this course does not count as a MEAM upper level.*

MEAM 514, IPD 514	Design for Manufacturability
EAS 545, IPD 545	Engineering Entrepreneurship I
EAS 546	Engineering Entrepreneurship II
ESE 400/540	Engineering Economics

Structural Mechanics & Mechanics of Materials

MEAM 508	Materials for Manufacturing
MEAM 519	Introduction to Elasticity
MEAM 527	Finite Element and Applications
MEAM 530	Continuum Mechanics
MEAM/MSE 220	Introduction to Materials Science and Engineering

Note:

- Courses may not be offered every year.
- Students may consider designing an independent study course, MEAM 099, with a MEAM faculty advisor in any area or across two or more areas.

COURSE DESCRIPTIONS

L/L means lecture and lab
L/R means lecture and recitation
(A) means generally taught in the Fall
(B) means generally taught in the Spring
(C) means generally taught both Fall and Spring
(M) means taught only occasionally

099. Independent Study. (C) Open to all students. A maximum of 2 c.u. of MEAM 099 may be applied toward the B.A.S. or B.S.E. degree requirements.
An opportunity for the student to become closely associated with a professor in (1) a research effort to develop research skills and technique and/or (2) to develop a program of independent in-depth study in a subject area in which the professor and student have a common interest. The challenge of the task undertaken must be consistent with the student's academic level. To register for this course, the student and professor jointly submit a detailed proposal. Subject to the approval of the MEAM Undergraduate Curriculum Chair.

L/L 101. Introduction to Mechanical Design. (C) This course is available to all Engineering majors.
This hands-on, project-based course covers the fundamentals of the modern mechanical design process, from needfinding and brainstorming to the basics of computerized manufacturing and rapid prototyping. Topics include: product definition (needfinding, observation, sketching, and brainstorming); computer-aided design (part creation, assemblies, and animation using SolidWorks); fundamental engineering design practices (material selection, dimensioning, tolerances, etc.); basic computer simulation and analysis; and rapid prototyping (laser cutter, 3-D fused-deposition modeling, and an introduction to computer-controlled machining).
**Please note: SEAS seniors are not permitted to register for this course. We encourage students to take this course early in their academic careers.*

L/R 110. Introduction to Mechanics. (A) Corequisite(s): MATH 104 (The Engineering section of this class is strongly recommended) and MEAM 147.
This lecture course and a companion laboratory course (MEAM 147) build upon the concepts of Newtonian (classical) mechanics and their application to engineered systems. This course introduces students to mechanical principles that are the foundation of upper-level engineering courses including MEAM 210 and 211. The three major parts of this course are: I. Vector Mechanics; II. Statics and Structures; and III. Kinematics and Dynamics. Topics include: vector analysis, statics of rigid bodies, introduction to deformable bodies, friction, kinematics of motion, work and energy, and dynamics of particles. Case studies will be introduced, and the role of Newtonian mechanics in emerging applications including bio- and nano-technologies will be discussed.

147. Introduction to Mechanics Lab. (A) Corequisite(s): MEAM 110.
This half-credit laboratory class is a companion to the Introduction to Mechanics lecture course (MEAM 110). It investigates the concepts of Newtonian (classical) mechanics through weekly hands-on experiments, emphasizing connections between theoretical principles and practical applications in engineering. In addition to furthering their understanding about the workings of the physical world, students will improve their skills at conducting experiments, obtaining reliable data, presenting numerical results, and extracting meaningful information from such numbers.

L/L 201. Machine Design and Manufacturing. (B) Prerequisite(s): MEAM 101, MEAM 210 or equivalent as co/pre-requisite (or permission of the instructor).
Building upon the fundamentals of mechanical design taught in MEAM 101, this hands-on, project-based course provides students with the knowledge and skills necessary to design, analyze, manufacture. and test fully-functional mechanical systems. Topics covered include an introduction to machine elements, analysis of the mechanics of machining, manufacturing technology, precision fabrication (milling, turning, and computer-controlled machining), metrology, tolerances, cutting-tool fundamentals and engineering materials. Enrollment is limited.

L/R 203. Thermodynamics I. (B) Prerequisite(s): Math 104 and Math 114. Corequisite(s): MEAM 248 for MEAM majors.
Thermodynamics studies the fundamental concepts related to energy conversion in such mechanical systems as internal and external combustion engines (including automobile and aircraft engines), compressors, pumps, refrigerators, and turbines. This course is intended for students in mechanical engineering, chemical engineering, materials science, physics and other fields. The topics include properties of pure substances, firs-law analysis of closed systems and control volumes, reversibility and irreversibility, entropy, second-law analysis, exergy, power and refrigeration cycles, and their engineering applications.

L/R 210. Statics and Strength of Materials. (A) Prerequisite(s): MEAM 110/147 or Physics 150. Corequisite(s): Math 240 and MEAM 247 are strongly recommended.
This course is primarily intended for students in mechanical engineering, but may also be of interest to students in materials science and other fields. It continues the treatment of statics of rigid bodies begun in MEAM 110/PHYS 150 and progresses to the treatment of deformable bodies and their response to loads. The concepts of stress, strain, and linearly elastic response are introduced and applied to the behavior of rods, shafts, beams and other mechanical components. The failure and design of mechanical components are discussed.

L/R 211. Engineering Mechanics: Dynamics. (B) Prerequisite(s): MEAM 210. Corequisite(s): MATH 241 or ENM 251 and ENGR 105 or equivalent. MEAM majors should take MEAM 248 as a Corequisite.
This course introduces the basic concepts in kinematics and dynamics that are necessary to understand, analyze and design mechanisms and machines. These concepts are also fundamental to the modeling and analysis of human movement, biomechanics, animation of synthetic human models and robotics. The topics covered include: Particle dynamics using energy and momentum methods of analysis; Dynamics of systems of particles; Impact; Systems of variable mass; Kinematics and dynamics of rigid bodies in plane motion; Computer-aided dynamic simulation and animation.

220. Introduction to Materials Science and Engineering. (A) Prerequisites: Knowledge of basic calculus and chemistry.
The course is an introduction to the most important concepts in materials science and engineering with a goal of building the foundations for all other courses related to materials and how to think about materials in other areas of engineering and the physical sciences. It covers atomic bonding, crystal structure and symmetry, glasses, defects, diffusion, elasticity, plasticity, fracture, phase diagrams, phase transformations, and an introduction into thermal, electrical, magnetic and optical properties and materials processing. Material classes will include metals, ceramics, polymers, semiconductors, and composites.

L/L 247. Mechanical Engineering Laboratory I. (A) Prerequisite(s): Sophomore standing in engineering. Corequisite(s): MEAM 210 strongly recommended.
This is the first of a two semester sophomore level laboratory sequence that students complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement as well as analysis and application to design. This fall semester course follows closely with MEAM 210, involving experiments to explore the principles of statics and strength of materials.

L/L 248. Mechanical Engineering Lab I. (B) Prerequisite(s): Sophomore standing in engineering. Corequisite(s): MEAM 203 and MEAM 211 are strongly recommended.
This is the second of a two-semester sophomore level laboratory sequence that students complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement as well as analysis and application to design. The spring semester course follows closely with MEAM 203 and MEAM 211, expanding upon the principles of experimentation, measurement, analysis, and design of systems through hands-on laboratories and projects in thermodynamics and dynamics.

L/R 302. Fluid Mechanics. (A) Prerequisite(s): MATH 241 or ENM 251 and PHYS 150 or MEAM 110/147.
Physical properties; fluid statics; Bernoulli equation; fluid kinematics; conservation laws and finite control-volume analysis; conservation laws and differential analysis; inviscid flow; The Navier-Stokes equation and some exact solutions; similitude, dimensional analysis, and modeling; flow in pipes and channels; boundary layer theory; lift and drag.

L/R 321. Vibrations of Mechanical Systems. (B) Prerequisite(s): MATH 241 or ENM 251 and MEAM 211.
This course teaches the fundamental concepts underlying the dynamics of vibrations for single-degree of freedom, multi-degree and infinite-degree of freedom mechanical systems. The course will focus on Newton's Force Methods, Virtual-Work Methods, and Lagrange's Variation Methods for analyzing problems in vibrations. Students will learn how to analyze transient, steady state and forced motion of single and multi-degree of freedom linear and non-linear systems. The course teaches analytical solution techniques for linear systems and practical numerical and simulation methods for analysis and design of nonlinear systems.

L/R 333. Heat and Mass Transfer. (B) Prerequisite(s): MEAM 203 and MEAM 302.
This course covers fundamentals of heat and mass transfer and applications to practical problems in energy conversion and conservation. Emphasis will be on developing a physical and analytical understanding of conductive, convective, and radiative heat transfer, as well as design of heat exchangers and heat transfer with phase change. Topics covered will include: types of heat transfer processes, their relative importance, and the interactions between them, solutions of steady state and transient state conduction, emission and absorption of radiation by real surfaces and radiative transfer between surfaces, heat transfer by forced and natural convection owing to flow around bodies and through ducts, analytical solutions for some sample cases and applications of correlations for engineering problems. Students will develop an ability to apply governing principles and physical intuition to solve problems.

L/L 347. Mechanical Engineering Design Laboratory. (A) Prerequisite(s): Junior standing in engineering.
This is the first of a two-semester junior level laboratory sequence that students complete over the fall and spring semesters. The course is project-based, with problems whose solution requires experimental data and quantitative analysis, as well as creative mechanical design. The technical content is connected to MEAM 302 and MEAM 354, including aerodynamics, applied fluid systems and structural analysis. The course also includes electromechanical systems and applications of finite element analysis.

L/L 348. Mechanical Engineering Design Laboratory. (B) Prerequisite(s): Junior standing in engineering.
This is the second of a two-semester junior level laboratory sequence that students complete over the fall and spring semesters. The course is project-based, with open-ended design problems that challenge students to develop original experiments and choose appropriate analyses, with an increasing emphasis on teamwork and project planning. The technical content is connected to MEAM 321 and MEAM 333, including multimodal transient heat transfer and dynamic systems modeling.

L/R 354. Mechanics of Solids. (A) Prerequisite(s): MEAM 210 or equivalent, BE200 or permission of instructor.
This course builds on the fundamentals of solid mechanics taught in MEAM 210 and addresses more advanced problems in strength of materials. The students will be exposed to a wide array of applications from traditional engineering disciplines as well as emerging areas such as biotechnology and nanotechnology. The methods of analysis developed in this course will form the cornerstone of machine design and also more advanced topics in the mechanics of materials.

405. (MEAM 505, MSE 405, MSE 505) Mechanical Properties of Macro/Nanoscale Materials. (A)
The application of continuum and microstructural concepts to consideration of the mechanics and mechanisms of flow and fracture in metals, polymers and ceramics. The course includes a review of tensors and elasticity with special emphasis on the effects of symmetry on tensor properties. Then deformation, fracture and degradation (fatigue and wear) are treated, including mapping strategies for understanding the ranges of material properties.

415. (IPD 515) Product Design. (C)
This course provides tools and methods for creating new products. The course is intended for students with a strong career interest in new product development, entrepreneurship, and/or technology development. The course follows an overall product design methodology, including the identification of customer needs, generation of product concepts, prototyping, and design-for-manufacturing. Weekly student assignments are focused on the design of a new product and culminate in the creation of a prototype. The course is open to juniors and seniors in SEAS or Wharton.

L/L 421. (ESE 421) Control for Autonomous Robots. (M) Prerequisite(s): Any one of CIS110, CIS120, or ENGR105; and any one of ESE 210, 215, or MEAM 211; or permission of instructor.
This course introduces the hardware, software and control technology used in autonomous ground vehicles, commonly called "self-driving cars." The weekly laboratory sessions focus on development of a small-scale autonomous car, incrementally enhancing the sensors, software, and control algorithms to culminate in a demonstration in a realistic outdoor operating environment. Students will learn basic physics and modeling; controls design and analysis in Matlab and Simulink; software implementation in C and Python; sensor systems and filtering methods for IMUs, GPS, and computer vision systems; and path planning from fixed map data.

445. Mechanical Engineering Design Projects. (A) Prerequisite(s): Junior standing.
This capstone design project course is required of all mechanical engineering students. Student teams will design and test complex mechanical systems that address a societal or consumer need. Projects are devised by the team, sponsored by industry, or formulated by Penn professors. Each project is approved by the instructor and a faculty advisor. Topics treated in the course include project planning, prototyping, patent and library searches, intellectual property, ethics, and technical writing and presentations. The work is spread over MEAM 445 and MEAM 446.

446. Mechanical Engineering Design Projects. (B)
This is the second course in the two course sequence involving the capstone design project. See MEAM 445.

455. (BE 455, MEAM 544) Continuum Biomechanics. (A)
Continuum mechanics with applications to biological systems. Fundamental engineering conservation laws are introduced and illustrated using biological and non-biological examples. Kinematics of deformation, stress, and conservation of mass, momentum, and energy. Constitutive equations for fluids, solids, and intermediate types of media are described and applied to selected biological examples. Class work is complemented by hands-on experimental and computational laboratory experiences.

502. Energy Engineering in Power Plants and Transportation Systems. (A) Prerequisite(s): MEAM 203 or equivalent, and MEAM 333 or equivalent.
Most energy consumed in the U.S. and in the world is produced using thermal-to-mechanical energy conversion. In this course, students will learn the engineering principles that govern how heat is converted to mechanical power in electric power plants, jet aircraft, and internal combustion engines. Topics covered include a review of thermodynamics and basic power cycles, supercritical, combined, and hybrid cycles, cogeneration, jet propulsion, and reciprocating internal combustion engines. A brief introduction to desalination and combustion is also included. The material in this course will provide students a foundation important for industrial and research employment in energy engineering.

L/R 503. Direct Energy Conversion: from Macro to Nano. (M)
The course focuses on devices that convert thermal, solar, or chemical energy directly to electricity, i.e., without intermediate mechanical machinery such as a turbine or a reciprocating piston engine. A variety of converters with sizes ranging from macro to nano scale will be discussed, with the advantages offered by nanoscale components specifically highlighted. Topics will include thermoelectric energy converters and radioisotope thermoelectric generators (RTGs), thermionic energy converters (TEC), photovoltaic (PV) and thermophotovoltaic (TPV) cells, as well as piezoelectric harvesters. Additional topics may include magnetohydrodynamic (MHD) generators, alkali metal thermal-to-electric converters (AMTEC), and fuel cells.

504. Tribology. (C) Prerequisite(s): Senior standing in Mechanical Engineering or Materials Science or by permission of the instructor.
The course will comprehensively cover both theoretical and practical tribology, the science and technology of interacting surfaces in relative motion. The various modes of lubrication, hydrodynamic, elastohydradynamic, hydrostatic, mixed, solid and dry, will be studied in detail. The contact between solid surfaces will be covered, leading to an understanding of friction and various modes of wear. At each stage, it will be shown how the tribological principles learned can be applied in practice to improve the efficiency and durability of mechanical equipment and thereby enhance sustainability through energy and materials conservation.

508. Materials Manufacturing For Mechanical Design. (B)
The selection of materials and manufacturing processes are critical in the design of mechanical systems. Material properties and manufacturing processes are often tightly linked, thus this course covers both topics in an integrated manner. The properties and manufacturing processes for a wide range of materials (i.e., metals, ceramics, polymers, composites) are examined from both a fundamental and practical perspective. From a materials standpoint, the course focuses on mechanical properties, including modulus, strength, fracture, fatigue, wear, and creep. Established and emerging manufacturing processes will be discussed. Design-based case studies are used to illustrate the selection of materials and processes.

L/L 510. Design of Mechatronic Systems. (A) Prerequisite(s): Junior or Senior standing in MEAM and a first course in Programming.
In many modern systems, mechanical elements are tightly coupled with electronic components and embedded computers. Mechatronics is the study of how these domains are interconnected, and this hands-on, project-based course provides an integrated introduction to the fundamental components within each of the three domains, including: mechanical elements (prototyping, materials, actuators and sensors, transmissions, and fundamental kinematics), electronics(basic circuits, filters, op amps, discrete logic, and interfacing with mechanical elements), and computing (interfacing with the analog world, microprocessor technology, basic control theory, and programming).

L/R 513. (ESE 505) Feedback Control Design and Analysis. (B) Prerequisite(s): MEAM 321 or ESE 210, Juniors and Seniors encouraged to enroll.
Basic methods for analysis and design of feedback control in systems. Applications to practical systems. Methods presented include time response analysis, frequency response analysis, root locus, Nyquist and Bode plots, and the state-space approach.

514. (IPD 514) Design for Manufacturability. (B) Prerequisite(s): MEAM 101 or equivalent, MEAM 210 or equivalent, Senior or Graduate standing in the School of Design, Engineering, or Business with completed product development and/or design engineering core coursework or related experience.
This course is aimed at providing current and future product design/development engineers, manufacturing engineers, and product development managers with an applied understanding of Design for Manufacturability (DFM) concepts and methods. The course content includes materials from multiple disciplines including: engineering design, manufacturing, marketing, finance, project management, and quality systems.

L/L 516. (IPD 516) Advanced Mechatronic Reactive Spaces. (M) Prerequisite: MEAM 510 (Mechatronics) or equivalent.
This course combines performance art and advanced mechatronics concepts that include the design and implementation of large-scale actuation, advanced sensing, actuation and control. This course pairs design school and engineering students to form interdisciplinary teams that together design and build electro-mechanical reactive spaces and scenic/architectural elements in the context of the performing arts. The two disciplinary groups will be treated separately and receive credit for different courses (ARCH746 will be taught concurrently and in some cases co-located) as they will be learning different things. Engineering students gain design sensibilities and advanced mechatronics in the form of networked embedded processing and protocols for large scale actuation and sensing. Design students learn elementary mechatronics and design reactive architectures and work with engineering students to build them. The class will culminate in a some artistic performance (typically with professional artists) such as a Shakespeare play, robotic ballet, a mechatronic opera.

519. (MSE 550) Elasticity and Micromechanics of Materials. (C)
This course is targeted to engineering students working in the areas on micro/nanomechanics of materials. The course will start with a quick review of the equations of linear elasticity and proceed to solutions of specific problems such as the Hertz contact problem, Eshelby's problem etc. Failure mechanisms such as fracture and the fundamentals of dislocations/plasticity will also be discussed.

520. Introduction to Robotics. (A) Prerequisite(s): MEAM 211 and MATH 240 or equivalent.
The rapidly evolving field of robotics includes systems designed to replace, assist, or even entertain humans in a wide variety of tasks. Recent examples include human-friendly robot arms for manufacturing, interactive robotic pets, medical and surgical assistive robots, and semi-autonomous search-and-rescue vehicles. This course presents the fundamental kinematic, dynamic, and computational principles underlying most modern robotic systems. The main topics of the course include: rotation matrices, homogeneous transformations, manipulator forward kinematics, manipulator inverse kinematics, jacobians, path and trajectory planning, sensing and actuation, feedback control, haptic interfaces, and teleoperation. The material is reinforced with hands-on lab exercises involving a robotic arm and a haptic interface.

L/R 527. Finite Element Analysis. (A) Prerequisite(s): MATH 241 or ENM 251 and PHYS 151.
The objective of this course is to equip students with the background needed to carry out finite elements-based simulations of various engineering problems. The first part of the course will outline the theory of finite elements. The second part of the course will address the solution of classical equations of mathematical physics such as Laplace, Poisson, Helmholtz, the wave and the Heat equations. The third part of the course will consist of case studies taken from various areas of engineering and the sciences on topics that require or can benefit from finite element modeling. The students will gain hands-on experience with the multi-physics, finite element package FemLab.

530. Continuum Mechanics. (B) Prerequisite(s): Multivariable Calculus, Linear Algebra, Partial Differential Equations.
This course serves as a basic introduction to the Mechanics of continuous media, and it will prepare the student for more advanced courses in solid and fluid mechanics. The topics to be covered include: Tensor algebra and calculus, Lagrangian and Eulerian kinematics, Cauchy and Piola-Kirchhoff stresses, General principles: conservation of mass, conservation of linear and angular momentum, energy and the first law of thermodynamics, entropy and the second law of thermodynamics; constitutive theory, ideal fluids, Newtonian and non-Newtonian fluids, finite elasticity, linear elasticity, materials with microstructure.

535. Advanced Dynamics. (A) Prerequisite(s): MEAM 211 and some Linear Algebra. Senior or Master's Standing in Engineering or permission of the instructor.
Three-Dimensional Geometry: Introduction to Reference Frames, Geometry of Rotations of Reference Frames and of Vectors, Euler Angle, Axis-Angle Representations, Properties of Rotation Matrices. Kinematics: Kinematics of Rigid-Body Motion, Rotations, Angular Velocity and Acceleration, Linear Velocity and Acceleration, Applications to Planar Linkage Analysis. Constraints: Configuration Space, Holonomic and Non-holonomic Constraints, Degrees of Freedom, Tests for Holonomic versus Non-holonomic Constraints, Generalized Coordinates, Generalized Speeds, Partial Speeds, Partial Velocities, Principle of Virtual Work for Holonomic and Non-holonomic systems. Constraint Forces: Virtual Work, D'Alembert Equations, Lagrange's Equations for Non-holonomic systems. Distribution of Mass: Center-of-Mass, Vector and Scalar Moments of Inertia. Vector Spaces: Operators, Dyads, Dyadic, Moment-of-Inertia Tensor, Rigid Bodies. Dynamics: Kinetic Energy and Angular Momentum, Lagrangian/Hamiltonian Mechanics and Conservation Laws, Poisson Brackets and Constants of the Motion, Kane-Lagrange Equations with Non-Holonomic Constraints, Kane-Lagrange Equations, Null Spaces and Computing Constraint Forces. Variational Calculus: The Principle of Least Action, A Study of Small Perturbations and Linear Stability Analysis.

536. Viscous Fluid Flow and Modern Applications. (M) This course is intended for juniors, seniors and graduate students from the Schools of Engineering and/or Arts and Sciences that have a general interest in fluid dynamics and its modern applications. Students should have an understanding of basic concepts in fluid mechanics and a good grasp on differential equations. This is an intermediate course that builds on the basic principles of Fluid Mechanics. The course provides a more in depth and unified framework to understand fluid flow at different time and length scales, in particular viscous flows. Topics include review of basic concepts, conservation laws (momentum, mass, and heat), fluid kinematics, tensor analysis, Stokes' approximations, non- Newtonian fluid mechanics, and turbulence. The course will explore important modern topics such as microfluidics, swimming of micro-organisms, wind turbines, rheology, biofluid mechanics, and boundary layers.

537. (MSE 537) Nanotribology. (B) Prerequisite(s): Freshman physics; MEAM 354 or equivalent, or consent of instructor.
Engineering is progressing to ever smaller scales, enabling new technologies, materials, devices, and applications. This course will provide an introduction to nano-scale tribology and the critical role it plays in the developing areas of nanoscience and nanotechnology. We will discuss how contact, adhesion, friction, lubrication, and wear at interfaces originate, using an integrated approach that combines concepts of mechanics, materials science, chemistry, and physics. We will cover a range of concepts and applications, drawing connections to both established and new approaches. We will discuss the limits of continuum mechanics and present newly developed theories and experiments tailored to describe micro- and nano-scale phenomena. We will emphasize specific applications throughout the course. Reading of scientific literature, critical peer discussion, individual and team problem assignments, and a peer-reviewed literature research project will be assigned as part of the course.

538. Turbulence. (M) Prerequisite(s): MEAM 302 or equivalent (a consult with the instructor before enrollment is encouraged for undergraduates).
This course is an introductory course on turbulent flows. The course provides physical and mathematical framework for quantitative and qualitative descriptions of fundamental processes involved in turbulent flows. Topics include the Navier-Stokes equations, the statistical description of turbulence, equations for mean and fluctuations, energy cascade, turbulence spectra, Kolmogorov hypotheses, behavior of shear flows, and isotropic turbulence. The course will also explore modern topics such as computational modeling of turbulence.

543. Performance, Stability and Control of UAVs. (C) Prerequisite(s): MEAM 210, 211, MATH 240 or equivalents. This course covers the application of classical aircraft performance and design concepts to fixed-wing and rotary-wing Unmanned Aerial Vehicles (UAVs). A survey of the latest developments in UAV technology will be used to motivate the development of quantitative mission requirements, such as payload, range, endurance, field length, and detectability. The implications of these requirements on vehicle configuration and sizing and will be revealed through application of the fundamentals of aerodynamics and propulsion systems. The course will also cover basic flight dynamics and control, including typical inner-loop feedback applications.

545. Aerodynamics. (B) Prerequisite(s): MEAM 302. Review of fluid kinematics and conservation laws; vorticity theorems; two-dimensional potential flow; airfoil theory; finite wings; oblique shocks; supersonic wing theory; laminar and turbulent boundary layers.

550. Design of Microelectromechanical Systems. (M) Prerequisite(s): MEAM 354 or equivalent is recommended. A course that covers the design and fabrication of micro- and nano-electromechanical systems. Topics in the course include micro- and nano-fabrication techniques, mechanics of flexures, thin film mechanics, sensing and actuation approaches (e.g., electrostatic, plezoelectric, and piezoresistive), as well as materials and reliability issues. The fundamentals of these topics will be augmented with device-based case studies.

L/R 561. Thermodynamics: Foundations, Energy, Materials. (M) Prerequisite(s): Undergraduate thermodynamics. To introduce students to advanced classical equilibrium thermodynamics based on Callen's postulatory approach, to exergy (Second-Law) analysis, and to fundamentals of nonequilibrium thermodynamics. Applications to be treated include the thermodynamic foundations of energy processes and systems including advanced power generation and aerospace propulsion cycles, batteries and fuel cells, combustion, diffusion, transport in membranes, materials properties and elasticity, superconductivity, biological processes.

L/L 564. (ESE 460, ESE 574) The Principles and Practice of Microfabrication Technology. (A) Prerequisite(s): Any of the following courses: ESE 218, MSE 321, MEAM 333, CHE 351, CHEM 321/322, PHYS 250 or permission of the instructor.
A laboratory course on fabricating microelectronic and micromechanical devices using photolithographic processing and related fabrication technologies. Lectures discuss: clean room procedures, microelectronic and microstructural materials, photolithography, diffusion, oxidation, materials deposition, etching and plasma processes. Basic laboratory processes are covered in the first two thirds of the course with students completing structures appropriate to their major in the final third. Students registering for ESE 574 will be expected to do extra work (including term paper and additional project).

L/R 570. (CBE 640) Transport Processes I. (A)
The course provides a unified introduction to momentum, energy (heat), and mass transport processes. The basic mechanisms and the constitutive laws for the various transport processes will be delineated, and the conservation equations will be derived and applied to internal and external flows featuring a few examples from mechanical, chemical, and biological systems. Reactive flows will also be considered.

575. Micro and Nano Fluidics. (M)
The course focuses on topics relevant for micro-fluidics, lab on chip technology, point of care diagnostics, nano-technology, biosensing, and interfacial phenomena. Although we will discuss briefly the fabrication of micro and nano fluidic devices, the course will mostly focus on physical phenomena from the continuum point of view. The mathematical complexity will be kept to a minimum. The course will be reasonably self-contained, and any necessary background material will be provided, consistent with the students' background and level of preparation. Specifically, we will examine fluid and nanoparticle transport under the action of pressure, electric, magnetic, and capillary forces; the structure and role of superhydrophobic surfaces; how the solid/liquid interface acquires electric charge; ion transport in electrolytes (Poisson-Nernst-Planck equations); colloid stability; electroosmosis, electrophoresis, and particle polarization; electrowetting and digital microfluidics; particle and cell sorting; immunoassays; and enzymatic amplification of nucleic acids.

PRIMARY FACULTY IN MECHANICAL ENGINEERING AND APPLIED MECHANICS

As of 8/1/18

Paulo E. Arratia, Professor and Associate Chair for Undergraduate Affairs
Office: 271 Towne Phone: 215-746-2174 Email: parratia@seas.upenn.edu

Micro- and Nanofluidics, Complex Fluids such as polymeric & biological materials, Transport Phenomena with emphasis on fluid & nonlinear dynamics, Rheology, and Soft-Condensed Matter including granular media.

Portonovo S. Ayyaswamy, Asa Whitney Professor of Dynamical Engineering
Office: 231 Towne Phone: 215-898-8362 Email: ayya@seas.upenn.edu

Phase change heat and mass transfer processes, bioheat/mass transfer, arc-plasma heat transfer, thermal aspects in MEMS.

Igor Bargatin, Class of 1965 Term Assistant Professor
Office: 277 Towne Phone: 215-746-4887 Email: bargatin@seas.upenn.edu

Micro- and nanomechanics, thermal sciences and energy conversion, mechanics of materials.

John L. Bassani, Richard H. and S. L. Gabel Professor of Mechanical Engineering
Office: 251 Towne Phone: 215-898-5632 Email: bassani@seas.upenn.edu

Plastic deformation of crystals, atomic/continuum property relationships, interface mechanics, fracture mechanics, material stability at large strains, mechanics of living cells.

Haim H. Bau, Professor
Office: 233 Towne Phone: 215-898-8363 Email: bau@seas.upenn.edu

Bifurcation and instability phenomena in and feedback control of flows, transport phenomena in micron and submicron size structures, meso- and microelectromechanical systems.

Robert Carpick, John Henry Towne Professor and Department Chair
Office: 237 Towne Phone: 215-898-4608 Email: carpick@seas.upenn.edu

Experimental nanomechanics and nanotribology (friction, adhesion, lubrication, wear). Development, characterization, and applications of nanostructured materials. Application and development of advanced scanning force microscopy tools.

Howard H. Hu, Professor and Master's Program Chair
Office: 241 Towne Phone: 215-898-8504 Email: hhu@seas.upenn.edu

Modeling of complex flows with multiphase or polymeric fluids, computational fluid dynamics, hydrodynamic stability.

Vijay Kumar, Nemirovsky Family Dean and Professor
Office: 107 Towne Phone: 215-898-3630 Email: kumar@seas.upenn.edu

Robotics, dynamics of systems with frictional contacts, actively coordinated mobility systems, mechanism design and control.

Noam Lior, Professor
Office: 212 Towne Phone: 215-898-4803 Email: lior@seas.upenn.edu

Heat transfer and fluid mechanics, thermodynamics and Second-Law analysis, energy conversion, solar energy, combustion, flash evaporation and water desalination, destruction of hazardous wastes by photocatalysis and supercritical oxidation, heat treatment.

Jennifer R. Lukes, Professor
Office: 247 Towne Phone: 215-898-3254 Email: jrlukes@seas.upenn.edu

Molecular dynamics simulation, molecular mechanical engineering, micro/nanoscale heat transfer.

George Ilhwan Park, Assistant Professor
Office: 524A, 3401 Walnut Phone: 215-898-5596 Email: gipark@seas.upenn.edu

Fluid mechanics, computational mechanics.

Paris Perdikaris, Assistant Professor
Office: 527A, 3401 Walnut Phone: 215-546-2993 Email: pgp@seas.upenn.edu

Computational Science and Engineering, Machine learning and Data-driven Modeling, Design under Uncertainty, High-performance Computing.

James Pikul, Assistant Professor
Office: 272 Towne Phone: 215-573-2786 Email: pikul@seas.upenn.edu

Energy storage and conversion, Multiscale transport
Nanomanufacturing, Multifunctional materials.

Pedro Ponte Castañeda, Professor and Raymond S. Markowitz Faculty Fellow
Office: 235 Towne Phone: 215-898-5046 Email: ponte@seas.upenn.edu

Nonlinear composite materials, fracture mechanics, microstructure evolution and localization in manufacturing processes, nonlinear variational principles in mechanics.

Michael Posa, Assistant Professor
Office: 276 Towne Phone: 215-746-6912 Email: posa@seas.upenn.edu

Robotics, Control Systems, Mechanical Systems.

Prashant Purohit, Professor
Office: 528A, 3401 Walnut Phone: 215-898-3870 Email: purohit@seas.upenn.edu

Rod theories for DNA and biopolymers, mechanics of sub-cellular organelles, mechanics at the bio-nano interface, martensitic phase transitions in solids.

Jordan Raney, Assistant Professor
Office: 274 Towne Phone: 215-573-9928 Email: raney@seas.upenn.edu

Mechanics of heterogeneous materials; new materials and hardware for 3D printing; nonlinear mechanics; soft materials; synthesis of nanostructures; structural hierarchy and bioinspiration; instabilities; programmed/robotic assembly of material architectures.

Celia Reina, William K. Gemmill Term Assistant Professor
Office: 523A, 3401 Walnut Phone: 215-898-9258 Email: creina@seas.upenn.edu

Computational Mechanics, Mechanics of Materials, Micro- and Nanomechanics.

Cynthia Sung, Gabel Family Term Assistant Professor
Office: 273 Towne Phone: 215-746-6057 Email: crsung@seas.upenn.edu

Computational Design, Robotics, Mechanical Systems.

Kevin Turner, Professor and MEAM Associate Chair for Graduate Affairs
Office: 245 Towne Phone: 215-573-7485 Email: kturner@seas.upenn.edu

Development and understanding of micro/nanoscale manufacturing processes, experimental and computational fracture and contact mechanics, small-scale adhesion mechanics, micro/nanoelectromechanical systems, mechanics of biological interfaces and cells

Mark Yim, Professor and Director of the Integrated Product Design Program
Office: 229A Towne Phone: 215-898-5269 Email: yim@seas.upenn.edu

Modular reconfigurable robots and locomotion, PolyBot; MEMS and batch fabrication techniques; brute force digital time optimal control.

AFFILIATED FACULTY AND LECTURERS

As of 8/1/18

JD Albert, Lecturer
Office: B12 Towne Phone: 215-573-3679 Email: jd@jdalbert.com

Jeffrey Babin, Professor of Practice and Associate Director of the Entrepreneurship Program Office: 308 Towne Phone: 215-573-0731 Email: jbabin@seas.upenn.edu

Peter Bressler, Adjunct Associate Professor of Integrated Product Design
Office: B12 Towne Phone: 215-898-3108 Email: pwbe@seas.upenn.edu

Michael Carchidi, Senior Lecturer
Office: 208 Towne Phone: 215-898-8342 Email: carchidi@seas.upenn.edu

Thomas A.V. Cassel, Practice Professor and Director of the Entrepreneurship Program
Office: 306 Towne Phone: 215-573-9016 Email: tcassel@seas.upenn.edu

Stuart Diamond, Lecturer, Engineering Entrepreneurship Program
Email: diamond@seas.upenn.edu

M. Ani Hsieh, Research Associate Professor
Office: 248 Towne Phone: 215-746-6449 Email: mhsieh@seas.upenn.edu

Andrew Jackson, Professor of Practice
Office: 222 Towne Phone: 215-746-4013 Email: andjac@seas.upenn.edu

Bruce Kothmann, Senior Lecturer
Office: 220 Towne Phone: 215-898-4817 Email: kothmann@seas.upenn.edu

Linda Kurth, Lecturer, Engineering Entrepreneurship Program
Office: 144 Towne Phone: 215-746-5097 Email: lindakur@seas.upenn.edu

Sarah Rottenberg, Executive Director of Integrated Product Design (SEAS and Design), and Adjunct Associate Professor (Department of Architecture, School of Design)
Office: 218 Towne Phone: 215-573-6543 Email: srot@seas.upenn.edu

Jenna Shanis, Lecturer, Integrated Product Design
Office: 144 Towne Email: jenna@peel-design.com

Paul Stegall, Lecturer
Office: 252 Towne Phone: 215-746-6665 Email: stegall@seas.upenn.edu

Graham Wabiszewski, Senior Lecturer
Office: 224 Towne Phone: 215-898-9347 Email: grahamw@seas.upenn.edu

ADMINISTRATIVE STAFF

As of 8/1/18

Maryeileen B. Griffith, Associate Director of Graduate Programs
Office: 229 Towne Phone: 215-898-2826 Email: mebg@seas.upenn.edu

Lauren Kemp, Undergraduate Program Coordinator
Office: 229 Towne Phone: 215-898-4825 Email: laurem@seas.upenn.edu

Peter Litt, Academic Coordinator
Office: 229 Towne Phone: 215-746-1818 Email: peterlit@seas.upenn.edu

Nora Powell, Administrative Coordinator
Office: 304 Towne Phone: 215-746-1818 Email: npowell@seas.upenn.edu

Sue Waddington Pilder, Office Manager and Assistant to the Chair
Office: 229 Towne Phone: 215-898-2770 Email: waddingt@seas.upenn.edu

TECHNICAL STAFF

As of 8/1/18

Peter Bruno, Educational Laboratory Coordinator
Office: 191 Towne Phone: 215-573-4374 Email: pbrun@seas.upenn.edu

Jason Pastor, Instrumentation Technician
Office: 191 Towne Phone: 215-898-2865 Email: jmpastor@seas.upenn.edu

Peter Szczesniak, Manager, Manufacturing and Fabrication Services
Office: 191 Towne Phone: 215-573-8150 Email: peterszc@seas.upenn.edu

Joe Valdez, Instrumentation Technician
Office: 191 Towne Phone: 215-898-4473 Email: vjoseph@seas.upenn.edu

University of Pennsylvania's Code of Academic Integrity

https://catalog.upenn.edu/pennbook/code-of-academic-integrity/

Since the University is an academic community, its fundamental purpose is the pursuit of knowledge. Essential to the success of this educational mission is a commitment to the principles of academic integrity. Every member of the University community is responsible for upholding the highest standards of honesty at all times. Students, as members of the community, are also responsible for adhering to the principles and spirit of the following Code of Academic Integrity.*

Academic Dishonesty Definitions

Activities that have the effect or intention of interfering with education, pursuit of knowledge, or fair evaluation of a student's performance are prohibited. Examples of such activities include but are not limited to the following definitions:

A. Cheating Using or attempting to use unauthorized assistance, material, or study aids in examinations or other academic work or preventing, or attempting to prevent, another from using authorized assistance, material, or study aids. Example: using a cheat sheet in a quiz or exam, altering a graded exam and resubmitting it for a better grade, etc.

B. Plagiarism Using the ideas, data, or language of another without specific or proper acknowledgment. Example: copying another person's paper, article, or computer work and submitting it for an assignment, cloning someone else's ideas without attribution, failing to use quotation marks where appropriate, etc.

C. Fabrication Submitting contrived or altered information in any academic exercise. Example: making up data for an experiment, fudging data, citing nonexistent articles, contriving sources, etc.

D. Multiple Submissions Submitting, without prior permission, any work submitted to fulfill another academic requirement.

E. Misrepresentation of Academic Records Misrepresentation of academic records: misrepresenting or tampering with or attempting to tamper with any portion of a student's transcripts or academic record, either before or after coming to the University of Pennsylvania. Example: forging a change of grade slip, tampering with computer records, falsifying academic information on one's resume, etc.

F. Facilitating Academic Dishonesty Knowingly helping or attempting to help another violate any provision of the Code. Example: working together on a take-home exam, etc.

G. Unfair Advantage Attempting to gain unauthorized advantage over fellow students in an academic exercise. Example: gaining or providing unauthorized access to examination materials, obstructing or interfering with another student's efforts in an academic exercise, lying about a need for an extension for an exam or paper, continuing to write even when time is up during an exam, destroying or keeping library materials for one's own use., etc.

* If a student is unsure whether his or her action(s) constitute a violation of the Code of Academic Integrity, then it is that student's responsibility to consult with the instructor to clarify any ambiguities.