UNDERGRADUATE STUDENT MANUAL

Department of Mechanical Engineering and Applied Mechanics

University of Pennsylvania

August 2021

**For students entering in Fall 2021 only. Students entering in other class years should consult the corresponding manual. **

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. It combines fundamental knowledge with a strong hands-on component. 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, pharmaceuticals, 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, many our students choose to pursue a master's degree in mechanical engineering or a related field at some point in their career, while a select few pursue doctoral degrees.

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 Academic Coordinator for Undergraduate Programs (Katie Knorr, kknorr@seas.upenn.edu, Towne 229).

Mail Folders

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

Accelerated Master's Program

Undergraduate students entering fall 2018 and after may apply to the Accelerated Master's (AM) Program; students may apply no earlier than after the completion of their second semester and no later than the drop deadline of their seventh semester. Students applying to the AM program must provide an intentional academic plan showing how they will complete their Penn Engineering undergraduate degree in eight semesters for single degree students, and ten semesters for coordinated dual-degree students. Students may take up to three graduate courses to fulfill both undergraduate and graduate degree requirements. To apply for the Accelerated Master's Program, submit an application with required materials, including a complete undergraduate course plan. 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.

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

ASME Student Chapter
https://fling.seas.upenn.edu/~asme/dynamic/wordpress/
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.

FLITE
https://flite.seas.upenn.edu/
FLITE (First-generation, Low-income students in Technology and Engineering) is a student organization that provides catered support, opportunities and development for First-generation, Low-income (FGLI) students at Penn passionate about technology and engineering to ensure success for a population with unique needs.
Email: flite@seas.upenn.edu

Hexagon Engineering Honors Society
https://www.seas.upenn.edu/~hexagon/
Hexagon Engineering Honor Society is a group of seniors who span across the various engineering disciplines and volunteer to give tours to high school students who are considering the School of Engineering.
Email: penn.hexagon@gmail.com

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.
Email: upennnsbeexternalaffairs@gmail.com

oSTEM at Penn
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).
Email: ostematpenn@gmail.com

Penn Aerial Robotics
https://www.pennaerial.com/
The mission of Penn Aerial Robotics is to engage undergraduate students of the University of Pennsylvania in the development of aerial robots and unmanned aerial vehicles. The club aims to do so by providing students with the resources to construct, develop and test robots, travel to and compete at inter-collegiate competitions, and connect with people who share this same passion.

Penn Aerospace Club
https://aerospaceclub.seas.upenn.edu/
The Penn Aerospace Club (PAC) aims to teach and excite the Penn community about aerospace engineering and the aerospace industry through projects, competitions, and speaker events.

Penn Electric Racing (PER)
https://www.pennelectricracing.com/
Penn Electric Racing is a completely student-run project with the purpose of designing, building, and racing clean energy vehicles. Students are involved in design, construction, management, fundraising and educational outreach.
Email: electric@seas.upenn.edu

Penn EWB- Engineers Without Borders
https://sites.google.com/view/pennewb/projects/local?authuser=0
The Penn chapter of Engineers Without Borders seeks to help its undergraduate members develop the skills and knowledge necessary to leave lasting social impact on a global scale.

SEAS Wellness
https://seaswellness.seas.upenn.edu/
SEAS Wellness is dedicated to improving student mental health and wellness in Penn Engineering. Our group focuses on advocating for students, spreading awareness about available resources, and researching how to improve student health and well-being for engineering students.
Email: seaswellness@seas.upenn.edu

Society of Asian Scientists & Engineers (SASE)
https://www.facebook.com/saseupenn
The Society of Asian Scientists & Engineers (SASE) is committed to helping STEM students achieve their full career potential through professional development, celebrating diversity, and giving back to our local communities. SASE is right at the intersection of culture, science, and technology. Join SASE for mentorship, community impact, and professional development events throughout the year!
Email: pennsase@gmail.com

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.
Email: sphe@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.
Email: pennswe@gmail.com

Women in MEAM (WiM)
https://www.facebook.com/WiMPenn/
Founded in the spring of 2019, Women in MEAM (WiM) is a group dedicated to fostering a sense of community and engagement amongst the female members of the Mechanical Engineering Department here at the University of Pennsylvania. We aim to create spaces that encourage respect and appreciation for the women in our department, acknowledging their accomplishments and their many talents. We understand how hard it can be to find a sense of belonging in the world of engineering, no matter who you are. All are welcome in our community!
Email: wim.upenn@gmail.com

A selection of additional student organizations is included below:

- Engineering Student Activities Council (ESAC)
- Engineering Dean's Advisory Board (EDAB)
- Underrepresented Student Advisory Board for Engineers
- Access Engineering
- Assistive Devices and Prosthetic Tech (ADAPT)
- Alpha Omega Epsilon (AOE)
- Engineering Deans' Advisory Board (EDAB)
- Engineers in Medicine (eMED)
- Management and Technology Student Board (M&T Board)
- Penn ACM SIGGRAPH
- Penn Engineering Council (PEC)
- Penn Tech Review (PTR)
- Rachleff Scholars Society
- Theta Tau

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

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 is some more information: https://abroad.seas.upenn.edu/steps-to-study-abroad/

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 aerodynamics, 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 37 course units distributed among six categories, as listed below:

10 credit units = Math and Natural Science courses

9 credit units = Core MEAM courses

4 credit units = Concentration courses

7 credit units = Professional Electives

\+ 7 credit units = General Electives

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37 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/

CURRICULUM OPTIONS AND CONCENTRATIONS

Students may choose to pursue a broad-based mechanical engineering curriculum through the general curriculum, taking prescribed courses that cover the traditional pillars of mechanical engineering theory and practice; or, students may choose to declare an optional concentration in one of three areas:

- Dynamics, Controls, and Robotics
- Energy, Fluids, and Thermal Systems
- Mechanics of Materials, Structures and Design

Students in the MEAM major will automatically default into the general curriculum unless they declare an optional concentration.

All MEAM majors must

- take 10 CUs of math and natural science requirements, as prescribed in the MEAM BSE requirements
- take 9 CUs of common MEAM core classes, beginning in the sophomore year
- take 3 CUs/3 courses of MEAM upper levels (defined as any MEAM 5xx course, excluding MEAM 599)
- pursue the 2 CU/two semester Senior Design sequence

Key differences between the general curriculum (no concentration declared) and the three optional concentration areas are

- In the junior year, students take either four prescribed 300-level MEAM courses covering fundamental theoretical foundations for mechanical engineering (general curriculum) *or* two prescribed 300-level MEAM courses related to their declared concentration, in addition to one "breadth" 300-level MEAM course in a foundational area not directly applicable to the concentration
- Students take either three MEAM upper levels of their choosing (general curriculum) *or* two MEAM upper levels of their choosing and one concentration-specific MEAM upper level

AREAS OF CONCENTRATION

Effective for students entering in Fall 2020 or after, students may select an *optional* concentration. Concentrations are intended to give students a more in-depth perspective into a particular area of focus within MEAM. Students will have the chance to declare their intention to follow a particular concentration, or continue with the "general" curriculum, during their sophomore year by filling out a concentration survey that will be sent by the department. The main goal of the concentration survey is to give students an opportunity to reflect and organize their path within the program/curriculum. Formal concentration declaration will be done in the senior year during senior course assessment prior to graduation. Only a single concentration choice will appear on a student's transcript. Students who do not wish to follow/declare a concentration must follow the "general" curriculum, which is the default for all incoming students; please see the UG Handbook for more details.

Students who do not declare their intention to follow one of the three optional concentrations must take a series of four prescribed foundational courses in their junior year:

- MEAM 302 Fluid Mechanics (1 CU) – Fall
- MEAM 321 Dynamic Systems and Control (1 CU) – Spring
- MEAM 333 Heat & Mass Transfer (1 CU) – Spring
- MEAM 354 Mechanics of Solids (1 CU) – Fall

**Courses appearing with an asterisk require permission of the instructor.*

Dynamics, Controls, and Robotics

Medical micro-robots, self-driving cars, interplanetary spacecraft, and hydrofoil catamarans critically rely on aspects of mechanical engineering. This concentration focuses on developing a practical and theoretical understanding of motion (dynamics) and algorithms for achieving desired motion (controls), along with the design and creation of just about anything that moves.

The Dynamics, Controls, and Robotics Concentration requires the completion of the following 4 CUs:

- MEAM 320 Intro to Mechanical and Mechatronic Systems (1 CU) – Fall
- MEAM 321 Dynamic Systems and Control (1 CU) – Spring
- MEAM 300-level breadth elective (choose any MEAM 300-level course beyond MEAM 320 and MEAM 321)
- Concentration-approved MEAM Upper-Level depth requirement (choose from the following list)
    - MEAM 510 Design of Mechatronic Systems
    - MEAM 513 Feedback Control Design and Analysis
    - MEAM 517 Control and Optimization with Applications in Robotics
    - MEAM 520 Introduction to Robotics
    - MEAM 535 Advanced Dynamics*
    - MEAM 543 Performance, Stability and Control of UAVs

Energy, Fluids, and Thermal Systems

Energy conversion and power generation, aerospace engineering, materials fabrication and manufacturing, cooling of microelectronic equipment, and thermal control and treatment of living organisms are critically important in today's economy. The MEAM Energy, Fluids, and Thermal Systems concentration is designed to provide the basic tools for dealing with these and other problems of current and future technological interest.

The Energy, Fluids, and Thermal Systems Concentration requires the completion of the following 4 CUs:

- MEAM 302 Fluid Mechanics (1 CU) – Fall
- MEAM 333 Heat & Mass Transfer (1 CU) – Spring
- MEAM 300-level breadth elective (choose any MEAM 300-level course beyond MEAM 302 and MEAM 333)
- Concentration-approved MEAM Upper-Level depth requirement (choose from the following list)
    - MEAM 502 Energy Engineering
    - MEAM 503 Direct Energy Conversion
    - MEAM 527 Finite Element Analysis
    - MEAM 536 Viscous Fluid Flow

- MEAM 545 Aerodynamics
- MEAM 561 Thermodynamics
- MEAM 580 Electrochemistry
- MEAM 570 Transport*
- MEAM 575 Micro and Nano Fluidics

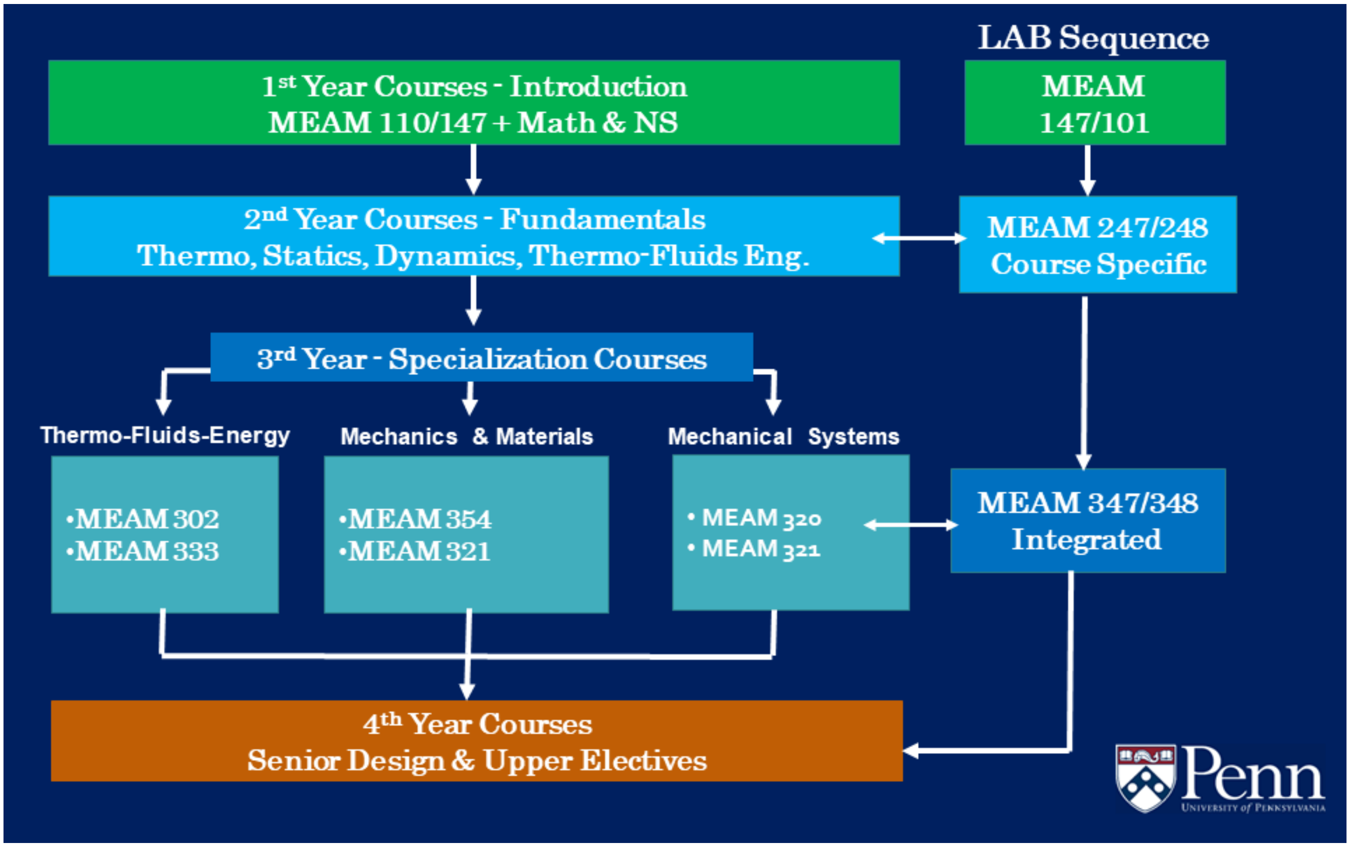
Mechanics of Materials, Structures and Design

Engineering materials, including metals, plastics, composites and biological tissues, are the building blocks of all engineered products. This concentration focuses on the experimental and mathematical characterization of the mechanical properties of these materials, as well as of the computation of internal forces (stresses) and deformations (strains) that develop on structures and mechanical devices made of these materials, either for design, manufacturing or performance evaluation including failure.

The Mechanics of Materials, Structures and Design Concentration requires the completion of the following 4 CUs:

- MEAM 321 Dynamic Systems and Control (1 CU) – Spring
- MEAM 354 Mechanics of Solids (1 CU) – Fall
- MEAM 300-level breadth elective (choose any MEAM 300-level course beyond MEAM 321 and MEAM 354)
- Concentration-approved MEAM Upper-Level depth requirement (choose from the following list)
  - MEAM 505 Mechanical Properties of Macro/Nanoscale Materials
  - MEAM 506 Failure Analysis of Engineering Materials
  - MEAM 507 Fundamentals of Materials
  - MEAM 508 Materials and Manufacturing
  - MEAM 519 Elasticity and Micromechanics of Materials*
  - MEAM 527 Finite Element Analysis

Below is a flow chart visualization of the MEAM curriculum.



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

For individualized course planning guides for the general curriculum and three concentrations, consult the appendix at the end of this manual.

MEAM COURSE PLANNING GUIDE (for students entering fall 2021)

Math and Natural Science (10 CU)

https://ugrad.seas.upenn.edu/student-handbook/courses-requirements/mathematics-courses/

https://ugrad.seas.upenn.edu/student-handbook/courses-requirements/natural-science-courses/

- ❒ **MATH 104 Calculus I**
- ❒ **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** or **ESE 112 Engineering Electromagnetics**
- ❒ **CHEM 101 Chemistry I** (Section 4, 5 or EAS 091) or **BIOL 121 Intro to Biology – The Molecular Biology of Life**
- ❒ **Math or Natural Science** [3]

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

MEAM Core (9 CU)*

- ❒ **MEAM 202 Intro to Thermal and Fluids Eng.**
- ❒ **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 347 ME Design Lab**
- ❒ **MEAM 348 ME Design Lab**
- ❒ **MEAM 445 Design Project I**
- ❒ **MEAM 446 Design Project II**

General Electives (7 CU) [4]

https://ugrad.seas.upenn.edu/student-handbook/courses-requirements/social-sciences-and-humanities-breadth/

https://ugrad.seas.upenn.edu/student-handbook/courses-requirements/technology-in-business-and-society-courses/

- ❒ **EAS 203 Eng. Ethics**
- ❒ Social Science
- ❒ Humanities
- ❒ Humanities
- ❒ Social Science or Humanities
- ❒ SS, H, or TBS
- ❒ SS, H, or TBS

4. One of these electives must fulfill the **Writing Requirement**: https://ugrad.seas.upenn.edu/student-handbook/courses-requirements/writing-requirement/

*Required if no concentration declared (4 CU):

- ❒ **MEAM 302 Fluid Mechanics**
- ❒ **MEAM 321 Dynamic Systems & Control**
- ❒ **MEAM 333 Heat & Mass Transfer**
- ❒ **MEAM 354 Mechanics of Solids**

Concentration Courses (4 CU) [5]

Dynamics, Controls, and Robotics

- ❒ MEAM 320 Intro to Mech & Mechatronic Sys
- ❒ MEAM 321 Dynamic Systems & Control
- ❒ MEAM 300-level Breadth Elective
- ❒ MEAM Upper Level [6]

Mechanics of Materials, Structures & Design

- ❒ MEAM 321 Dynamic Systems & Control
- ❒ MEAM 354 Mechanics of Solids
- ❒ MEAM 300-level Breadth Elective
- ❒ MEAM Upper Level [6]

Energy, Fluids, and Thermal Systems

- ❒ MEAM 302 Fluid Mechanics
- ❒ MEAM 333 Heat & Mass Transfer
- ❒ MEAM 300-level Breadth Elective
- ❒ MEAM Upper Level [6]

5. Students may only declare one concentration.
6. Students must choose from the list of concentration-approved courses (see MEAM undergraduate manual).

Professional Electives (7 CU) [7]

- ❒ ENGR 105 Intro to Scientific Computing [8]
- ❒ MEAM Upper Level____________ [9]
- ❒ MEAM Upper Level____________ [9]
- ❒ MEAM Upper Level____________ [9, 10]
- ❒ Technical Elective____________ [11]
- ❒ Technical Elective____________ [11]
- ❒ Technical Elective____________ [11, 12]

7. Maximum of three 100-level courses.
8. CIS 110 and CIS 120 are also acceptable.
9. Choose from all MEAM 500-level courses, excluding MEAM 599.
10. If declaring a concentration, choose from a MEAM Upper level or a Technical Elective.
11. Math, Natural Science, or Engineering categories. We recommend MEAM 101 and MEAM/MSE 220.
12. One Technical Elective may be satisfied with advanced dual degree requirements (with approval).

Note:
Bold courses are required MEAM courses.

MEAM B.S.E. SAMPLE FOUR-YEAR COURSE PLAN (GENERAL CURRICULUM)

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 their academic advisor.

Freshman Year

CUs	FALL	
1.5	**MEAM 110/147**	Intro to Mechanics & Lab
1	**MATH 104/004**	Calculus I & Lab
1	**CHEM 101**	Intro to Chemistry *or*
	BIOL 121	Intro to Biology
1	Social Science/Humanities elective	
Note:	**Students with AP credit should consider taking ENGR 105 or MEAM 101**	

CUs	SPRING	
1.5	**PHYS 151**	Principles of Physics II & Lab *or*
	ESE 112	Eng. Electromagnetics
1	**MATH 114/014**	Calculus II & Lab
1	Technical elective, such as MEAM 101	
1	Writing requirement	

Sophomore Year

CUs	FALL	
1	**MEAM 202**	Intro to Thermal and Fluids Engineering
1	**MEAM 210**	Statics & Strength of Materials
0.5	**MEAM 247**	Mech. Engineering Lab I
1	**MATH 240/024**	Calculus III & Lab
1	ENGR 105	Intro to Scientific Computing *or* another programming course

CUs	SPRING	
1	**MEAM 203**	Thermodynamics
1	**MEAM 211**	Engineering Mechanics: Dynamics
0.5	**MEAM 248**	MEAM Laboratory I
1	**ENM 251** **MATH 241**	Analytical Methods for Eng. *or* Calculus IV
1	**EAS 203**	Engineering Ethics

Junior Year

CUs	FALL	
1	**MEAM 302**	Fluid Mechanics
1	**MEAM 354**	Mechanics of Solids
1	**MEAM 347**	Mechanical Engineering Design Lab
1	Math elective	
1	Social Science/Humanities elective	

CUs	SPRING	
1	**MEAM 321**	Dynamic Systems & Control
1	**MEAM 333**	Heat & Mass Transfer
1	**MEAM 348**	Mechanical Engineering Design Lab
1	Math or Natural Science elective	
1	Social Science/Humanities elective	

Senior Year

CUs	FALL	
1	**MEAM 445**	Mechanical Engineering Design Projects
1	Upper-level MEAM course	
1	Upper-level MEAM course	
1	Technical elective	
1	Social Sciences/Humanities/TBS elective	

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

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

MEAM ELECTIVE SCHEDULE

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

Fall 2021 Electives

MEAM 101	Intro to Mechanical Design
MEAM/MSE 220	Introduction to Materials Science and Engineering
MEAM 411	How to Make Things: Production Prototyping Studio
MEAM 415, IPD 515, OIDD 415	Product Design
MEAM 421, ESE 421	Control for Autonomous Robots
MEAM 503	Direct Energy Conversion: from Macro to Nano
MEAM 504	Tribology
MEAM 506, MSE 506	Failure Analysis of Engineering Materials
MEAM 507, MSE 507	Fundamentals of Materials
MEAM 508	Materials and Manufacturing for Mechanical Design
MEAM 510	Design of Mechatronic Systems
MEAM 520	Introduction to Robotics
MEAM 545	Aerodynamics
MEAM 555, CBE 555, BE 555	Nanoscale Systems Biology
MEAM 570	Transport Processes I
ENM 360	Introduction to Data-driven Modeling
EAS 401/EAS 501	Energy and Its Impacts **fulfills TBS*
EAS 545, IPD 545	Engineering Entrepreneurship I **fulfills TBS*
EAS 546	Engineering Entrepreneurship II **fulfills TBS*

Tentative Spring 2022 Electives

MEAM 101	Introduction to Mechanical Design
MEAM 201	Machine Design and Manufacturing
MEAM 225	Engineering in the Environment
MEAM 415, IPD 515, OIDD 415	Product Design
MEAM 505, MSE 405/505	Mechanical Properties of Macro/Nanoscale Materials
MEAM 513, ESE 505	Feedback Control Design and Analysis
MEAM 514, IPD 514	Design for Manufacturability
MEAM 520	Introduction to Robotics
MEAM 529	Introduction to Micro- and Nano-electromechanical Technologies
MEAM 536	Viscous Fluid Flow
MEAM 538	Turbulence
MEAM 543	Performance, Stability and Control of UAVs
MEAM 546	Hovering Vehicle Design and Analysis Techniques
MEAM 575	Micro and Nano Fluidics
ENGR 105	Introduction to Scientific Computing
ENM 511	Foundations in Engineering Math II
ENM 520	Principles and Techniques of Applied Math
ENM 522	Numerical Methods for PDEs
ENM 531	Data-driven Modeling and Probabilistic Scientific Computing
EAS 402/EAS 502	Renewable Energy and Its Impacts **fulfills TBS*
EAS 545, IPD 545	Engineering Entrepreneurship I **fulfills TBS*
EAS 546	Engineering Entrepreneurship II **fulfills TBS*

RECOMMENDED ELECTIVES OUTSIDE OF MEAM

ASTR 211	Introduction to Astrophysics I
BIOL 101	Introduction to Biology
BE 514, IPD 504	Rehabilitation Engineering and Design
CBE 150	Intro to Biotechnology
CIS 110	Introduction to Computer Programming
CIS 120	Programming Languages and Techniques
CIS 160	Mathematical Foundations of Computer Science
CIS 240	Introduction to Computer Systems
ESE 210	Intro to Dynamic Systems
ESE 215	Electrical Circuits and Systems (1.5 CU, with lab)
ESE 301	Engineering Probability
ESE 305	Foundations of Data Science
ENM 360	Introduction to Data-driven Modeling
GEOL 204	Global Climate Change
GEOL 318	Glaciers, Ice and Climate
MATH 312	Linear Algebra
MATH 432	Game Theory
MSE 221	Quantum Physics of Materials
MSE 220	Introduction to Materials Science and Engineering
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
STAT 430	Probability

MEAM COURSE DESCRIPTIONS

L/L means lecture and lab
L/R means lecture and recitation
L/R/L means lecture, recitation, and lab
(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.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. Seniors are not permitted to register for this class.
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).

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. (C) Prerequisite(s): MEAM 101.
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 202. Introduction to Thermal and Fluids Engineering. (A) Prerequisite(s): Math 104 and MEAM 110 or PHYS 150. Corequisite(s): MATH 114.
This course introduces students to the main concepts and applications of thermodynamics, fluid mechanics, and heat transfer. Topics covered include the first law of thermodynamics, fluid statics, Bernoulli's equation, drag, lift, streamlines, conduction, convection, radiation, thermal resistances, and lumped capacitance. Mass, momentum, and energy equations are developed using the Reynolds Transport Theorem.

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 and MATH 240 and ENGR 105. Corequisite(s): MATH 241 or ENM 251. 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: CHEM 101 or PHYS 140 or MEAM 110.
The course is an introduction to the most important concepts in materials science and engineering. You will learn how the control of chemical bonding, synthesis, processing, structure and defects can be used to tailor the properties and performance of materials for applications that range from sustainable sources of energy, to construction, to consumer electronics. Case studies are also included to highlight environmental issues associated with materials degradation. This course includes lab demonstrations of key materials properties and a final project where students research an area of materials technology of their own interest.

225. Engineering in the Environment. (M) Prerequisites: MATH 114 AND PHYS 150
This course will lead with applications related to the environment and climate change, and use simple scaling and dimensional analysis to develop physical intuition. Students will be introduced to topics such as mechanics (e.g., failure) and flow of soil and rock, river erosion, and transport and dispersion of contaminants in water and air, as well as basic phenomena of weather and climate. The primary objective for this course is that students discover how to apply basic engineering insight to non-engineered (i.e., natural), unconstrained systems. A secondary objective is to entice mechanical engineers to become interested in the environment.

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 320. Intro to Mechanical and Mechatronic Systems. (A) Prerequisite(s): MEAM 211. Corequisite(s): MEAM 347.
This course introduces topics in the design and analysis of modern mechanical systems. The course will cover concepts in mechanism design, kinematics, electronic circuits, motors and electromechanical systems, and measurement and filtering. Specific topics include kinematics of linkages, operational amplifiers, and interfacing with mechanical systems by programming microcontrollers.

L/R 321. Dynamic Systems and Control. (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.

411. How to Make Things: Production Prototyping Studio. (A)
The course centers around a sequence of three projects that each culminate in the design and fabrication of functional objects. A 2D Design, 3D Design, and final "Micro-Manufacturing" project will introduce students to a wide variety of design, engineering, and fabrication skills made possible by the new Studios @ Tangen Hall. The micro-manufacturing final project will task interdisciplinary student teams to create a "micro-business" where they will design and utilize 3D printed molding and casting techniques to create a small-scale run of functional products. These products will then be showcased in an end of semester exposition, where the teams will merchandise and market their products to the Penn community. This exposition will also be a wonderful inaugural use of the student and alumni retail space on the 1st floor of Tangen Hall and serve as a great university-wide event to show case the work of SEAS students. Requires proficiency in solid modeling software (e.g., SolidWorks, Maya, Rhino), practice with design process, and hands-on fabrication experience.

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, which is launched at an end-of-semester public Design Fair. The course project is a physical good - but most of the tools and methods apply to services and software products. The course is open to any Penn sophomore, junior, senior or graduate student.

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.

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. (A) Prerequisite(s): Basics of thermodynamics (MEAM 203 or equivalent), basics of heat transfer (MEAM 333 or equivalent).
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. (A) Prerequisite: Senior standing in Mechanical Engineering or Material Science or 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, elastohydrodynamic, 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. (M)

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/R 510. Design of Mechatronic Systems. (C) 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/L 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 an artistic performance (typically with professional artists) such as a Shakespeare play, robotic ballet, a mechatronic opera.

519. (MSE 550) Elasticity and Micromechanics of Materials. (A) Prerequisite: graduate standing or permission of the instructor.

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. Working knowledge of MATLAB will be very useful.
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, and feedback control. The material is reinforced with hands-on lab exercises involving a robotic arm.

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. Graduate standing 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. (B) 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. (M) 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 570 and MEAM 536 or equivalents. Permission of the instructor required 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. (A) 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 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.

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.

570. 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. Prerequisite: graduate standing or permission of the instructor.

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.

ENGR 105. Introduction to Scientific Computing. (C)
This course will provide an introduction to computation and data analysis using MATLAB - an industry standard programming and visualization environment. The course will cover the fundamentals of computing including: variables, functions, decisions, iteration, and recursion. These concepts will be illustrated through examples and assignments which show how computing is
applied to various scientific and engineering problems. Examples will be drawn from the simulation of physical and chemical systems, the analysis of experimental data, Monte Carlo numerical experiments, image processing, and the creation of graphical user interfaces. This course does not assume any prior programming experience but will make use of basic concepts from calculus and Newtonian physics.

L/R ENM 251. Analytical Methods for Engineering. (B) Prerequisite(s): MATH 240.
This course introduces students to physical models and mathematical methods that are widely encountered in various branches of engineering. Illustrative examples are used to motivate mathematical topics including ordinary and partial differential equations, Fourier analysis, eigenvalue problems, and stability analysis. Analytical techniques that yield exact solutions to problems are developed when possible, but in many cases, numerical calculations are employed using programs such as Matlab and Maple. Students will learn the importance of mathematics in engineering. Prerequisite: Sophomore standing in SEAS or permission of instructor(s).

ENM 360. Introduction to Data-driven Modeling. (A) Prerequisite(s): ENGR 105, MATH 240.
From recognizing voice, text or images to designing more efficient airplane wings and discovering new drugs, machine learning is introducing a transformative set of tools in data analysis with increasing impact across engineering, sciences, and commercial applications. In this course, you will learn about principles and algorithms for extracting patterns from data and making effective automated predictions. We will cover concepts such as regression, classification, density estimation, feature extraction, sampling and probabilistic modeling, and provide a formal understanding of how, why, and when these methods work in the context of analyzing physical, biological, and engineering systems.

PRIMARY FACULTY IN MECHANICAL ENGINEERING AND APPLIED MECHANICS

As of 8/2021

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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.

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

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

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

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Robotics, nonlinear dynamical systems, multi-robot systems, environmental monitoring, marine robotics, distributed planning, coordination, and control, and adaptive sampling.

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

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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.

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

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

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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 Department Chair
Office: 237 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.

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Peter Szczesniak, Manager, Manufacturing and Fabrication Services
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Joe Valdez, Instrumentation Technician
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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.

APPENDIX

Course Planning Guide (General Curriculum—no concentration declared)
Course Planning Guide (Dynamics, Controls, and Robotics concentration)
Course Planning Guide (Mechanics of Materials, Structures and Design concentration)
Course Planning Guide (Energy, Fluids, and Thermal Systems concentration)