ABET
Self-Study Report

for the

Mechanical Engineering Program

at

Yale University

New Haven, CT

July 31, 2020

CONFIDENTIAL

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Program Self-Study Report
for
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Accreditation or Reaccreditation

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B. Program History

Instruction in engineering at Yale was given in the Sheffield Scientific School, starting in 1852, making it one of the oldest engineering programs in the United States. The Mechanical Engineering program was implemented at Yale around 1865. In 1936, the Engineers' Council for Professional Development (ECPD – ABET's predecessor) accredited chemical, civil, electrical, mechanical, and metallurgical engineering programs in Yale's School of Engineering. While the civil and metallurgical engineering programs have been suspended, Yale continues to have ABET-accredited programs in mechanical, electrical, and chemical engineering.

In 2010, to more accurately reflect the scope of research activities and degree offerings, the Department officially changed its name to Mechanical Engineering & Materials Science.

The last General Program Review was in 2014. The Mechanical Engineering Program received reaccreditation for 6 years extending to September 30, 2020 following the General Program Review in 2014.

Major changes to Yale Engineering since 2014:

2015 The Yale Department of Computer Science joins the Yale School of Engineering & Applied Science to increase collaboration and create a closer connection between engineering and computing disciplines. The development includes a commitment to increase the number of Computer Science faculty by seven positions over the next few years.

2016 The School of Engineering & Applied Science (SEAS) completes the 15,000-square-foot renovation of the final two floors (of the former Yale Health building) at 17 Hillhouse to serve as research labs, faculty offices, and student work space for the Department of Chemical and Environmental Engineering. In addition, the building houses the Engineering Librarian as well as consultation and instructional space for library needs. This development marks the conclusion of a six-year process to repurpose and renovate this building.

2017 The Greenberg Engineering Teaching Concourse, composed of eight new undergraduate teaching labs, storage area, and a lab administrative office, opens, co-locating lab instruction for all engineering programs. The new labs have been designed — and are operated — to maximize flexibility in the space, where each lab space can be used to support multiple lab courses. This flexibility increases the utilization rate of the spaces with support systems established to maximize efficiency. Course-specific equipment is provided within the spaces and is stored in adjacent laboratory preparation rooms when not being used.

At the end of the year, Dean Kyle Vanderlick concludes a decade of service to the Yale School of Engineering & Applied Science in many dimensions, including securing a $50 million donation from SEAS alum John Malone to endow 10 new professorships, with this gift being the largest in the School's history. During her deanship, she also created the Yale Center for Engineering Innovation & Design (CEID) and secured the stability of the space with $23 million support from SEAS alum Dr. James S. Tyler. Furthermore, the Greenberg Engineering Teaching Concourse was completed under the leadership of Dean Vanderlick. Finally, she led a university-wide project to renovate the building known as 17 Hillhouse, with the former Yale Health building now serving as a thriving academic and research center on the Yale Engineering campus.

2018 Mechanical Engineering Professor Mitchell Smooke is appointed as Interim Dean of the Yale School of Engineering & Applied Science.

The Report of the University Science Strategy Committee, commissioned by Yale's President Peter Salovey, identifies five priority areas for the University to focus on: integrative data science, quantum science, neuroscience, inflammation, and environmental and evolutionary sciences. The report also recommends four cross-cutting investments: graduate student support, diversity throughout the STEM pipeline, instrumentation development, and core facilities. The report emphasizes "the need for Yale to have strength and intellectual coverage in areas of engineering and applied science." Specifically addressing the Yale School of Engineering & Applied Science, the report supports the "Engineering + X strategy for the future of SEAS," with the school having a hub-and-spokes structure across the University.

2019 Dean Jeffrey Brock is appointed to lead the Yale School of Engineering & Applied Science. Dean Brock, the Zhao and Ji Professor of Mathematics and the Dean of Science in the Faculty of Arts and Sciences, will serve as the single leader of Yale's engineering, applied science, and science programs. In that role, Dean Brock leads strategic thinking about the connection across science and engineering. As an internationally recognized data scientist and mathematician, Dean Brock has collaborated in substantial research partnerships with computer scientists. As Yale's leader of science and engineering, he will help implement Yale's strategy for these disciplines as established in the Report of the University Science Strategy Committee.

Construction begins on the Tsai Center for Innovative Thinking at Yale (Tsai CITY), a 12,500-square-foot building adjoining the CEID. Under the supervision of Yale's Provost, the new center will support students from diverse backgrounds and disciplines seek innovative ways to address real-world problems. As described by Yale's President Salovey, the CEID, the Greenberg Engineering Teaching Concourse, and Tsai CITY establish Yale's Innovation Corridor as a new model to catalyze innovation, creativity, and discovery.

2020 Provost Scott Strobel is appointed as Yale's Provost, replacing Professor Ben Polak who served as Yale's Provost from 2012 to 2019. Provost Strobel, the Henry Ford II Professor of Molecular Biophysics and Biochemistry, had previously chaired the University Science Strategy Committee, led the development of Yale's Poorvu Center for Teaching and Learning, and was Yale's Vice President for West Campus Planning and Program Development where he guided all aspects of a remote 136-acre site for research and learning.

The Yale Department of Applied Physics joins the Yale School of Engineering & Applied Science. Among other benefits, the inclusion of Applied Physics within the School of Engineering & Applied Science facilitates collaboration regarding quantum science, which was one of the priorities in the Report of the University Science Strategy Committee.

Major changes to Yale Mechanical Engineering since 2014:

For the Mechanical Engineering Program, the number of faculty has increased just slightly since 2014 (12.5 faculty members in 2014 and 13.5 in 2020), but there has been a significant change in the composition of the faculty. Nicholas Ouellette and Eric Dufresne have departed the Department, while Madhusudhan Venkadesan, Rebecca Kramer-Bottiglio, and Diana Qiu have been hired as Assistant Professors. The new faculty hires bring research and teaching expertise in biomechanics and mechatronics (Venkadesan), soft robotics (Kramer-Bottiglio), and tunable quantum materials (Qiu). Since 2014, several faculty members have received promotions. Professor Cha was promoted from Assistant to Associate Professor on Term. Professor Dollar received tenure and was promoted from Associate Professor on Term to Full Professor. Professor O'Hern was promoted from Associate Professor with tenure to Full Professor. The Department leadership has remained unchanged: Prof. Udo Schwarz is still Chair, Prof. Corey O'Hern is still the Director of Undergraduate Studies (DUS), and Prof. Jan Schroers is still the Director of Graduate Studies.

C. Options

Three undergraduate degrees are offered in the Department.

- B.S. in Mechanical Engineering (ABET-Accredited)
- B.S. in Engineering Sciences (Mechanical)
- B.A. in Engineering Sciences (Mechanical)

Three graduate degrees are offered.

- M.S. in Engineering and Applied Science
- M.Phil. in Engineering and Applied Science
- Ph.D. in Engineering and Applied Science

Accreditation is sought only for the B.S. in Mechanical Engineering.

D. Program Delivery Modes

The Mechanical Engineering major is offered as a day program.

E. Program Locations

The only location for this Program is in New Haven, CT.

F. Deficiencies, Weaknesses, or Concerns from Previous Evaluation(s) and the Actions Taken to Address Them

No deficiencies, weaknesses, or concerns were included in 2014 Final Statement.

GENERAL CRITERIA

CRITERION 1. STUDENTS

A. *Student Admissions*

All students admitted to Yale College are free to select any program of study, including engineering. The Admissions Office examines more than 38,000 applications yearly to form a class of approximately 1,500 students. (See Table 1-1 below.) The first-year class increased from 1373 to 1580 from 2016–2017 to 2017–2018 with the opening of two new residential colleges in the fall 2017 — the only increase in the undergraduate student population since 1969. The Office of Admissions looks for academic ability and achievement combined with other attributes such as motivation, curiosity, energy, and leadership ability. No simple profile of grades, scores, and activities guarantees admission. In recent years, over 400 students expressing an interest in engineering have been admitted, and slightly over half matriculate to yield approximately 250 first-year students interested in engineering. First-years are regularly admitted with advanced standing in a number of subjects including Chemistry, Mathematics, and Physics. Such students usually start in advanced courses in these subjects, and often take introductory engineering courses in their first year. First-year students interested in engineering are strongly encouraged to take engineering prerequisite courses in their first year.

Table 1-1. Number of new students enrolled in Yale College over the past five years and their corresponding test scores.

Academic Year	Middle 50% ACT		Middle 50% SAT		% of Students in Top 10%	Number of New Students Enrolled
	25%	75%	25%	75%		
2015–2016	31	35	710	800	95%	1,364
2016–2017	32	35	710	800	95%	1,373
2017–2018	32	35	710	800	96%	1,580
2018–2019	33	35	720	790	95%	1,578
2019–2020	33	35	720	790	92%	1,554

Students interested in Mechanical Engineering declare their major before the end of their second year at Yale. In addition to the ABET-accredited B.S. in Mechanical Engineering degree, the Department also offers a B.S. and B.A. in Engineering Sciences-Mechanical. The numbers of Mechanical Engineering majors, as well as Engineering Sciences-Mechanical majors, for the past five years are provided in Table 1-2. (The data for the classes of 2021 and 2022 is anticipated based on the students' current declared majors.) The number of students in the Mechanical Engineering Program has remained in the range 15–25 over the past several years.

Table 1-2. Numbers of recent Mechanical Engineering majors.

Year	Number of Mechanical Engineering Majors	Total Number of Majors in the Department
2016	20	38
2017	17	36
2018	15	37
2019	25	48
2020	17*	39
2021	17	39
2022	23	38

* One of the students will finish the requirements for the Program after Summer 2020, and one of the students will finish the requirements for the Program after the Fall 2020 semester.

B. Evaluating Student Performance

The requirements for the bachelor's degree in Yale College are a total of thirty-six course credits, the fulfillment of the distributional requirements, including the foreign language requirement, and the completion of a major program. Course credits and the distributional requirements are supervised by the Registrar's Office, the Residential College Deans, and the Yale College Dean's Office. One of the roles of the Director of Undergraduate Studies (DUS) is to certify to the Registrar that seniors have completed the requirements of the major program. Additional information on the responsibilities of the DUS is presented in Section D (Advising and Career Guidance) later in this chapter.

The DUS certifies whether a student has satisfied the requirements for the B.S. degree in Mechanical Engineering, which is accredited by the Engineering Accreditation Commission of ABET, Inc. In addition, the DUS forwards to the Committee on Honors and Academic Standing the nominations of the department or program for Distinction in the Major. Four out of seventeen Mechanical Engineering majors received Distinction in the Major in Academic Year 2019–2020. The DUS also oversees the administration of any prizes awarded by the department or program to graduating seniors. The senior academic prizes for the Department of Mechanical Engineering & Materials Science (MEMS) are the Donald Warren McCrosky Prize, awarded for great distinction in scholarly achievement in fields related to mechanics and its applications, and the L.C. Lichty and E.O. Waters Prize, awarded for high scholarship and original research. No student can graduate until the DUS has certified that he or she has fulfilled the requirements of the major program. The procedures for such certification differ at the end of the fall term and at the end of the spring term.

For fall certification, seniors who complete the degree requirements at the end of the fall term do not actually receive the degree until Commencement in May. They are cleared for the degree as soon as possible after the end of the fall term, however, so that their transcripts can show that they qualify for graduation in May. Such certification by the DUS that seniors have completed the requirements of the major at the end of a fall term is given on the Major Completion List (MC List). An MC List containing the names of seniors expected to complete degree requirements at the end of a fall term is sent to the DUS in January. (Departments with no seniors completing degree requirements at the end of a fall term will not receive an MC List.) Toward the end of January the DUS receives the updated academic records of these seniors, showing all their courses and grades through the end of the fall term. The DUS fills out and returns the Major Completion List, writing "SAT" next to the name of seniors who have completed all the requirements of the major, as well as the senior requirement. For the B.S. degree in Mechanical Engineering, the capstone senior design course sequence, MENG 487L and MENG 488L, satisfy the senior requirement.

For spring certification, because of the time pressures before graduation, this certification occurs in two steps: (1) the DUS gives the Registrar's Office provisional certification before grades are actually due; and (2) the Registrar's Office, in the absence of a subsequent negative correction from the DUS, confirms the certification when passing final course grades are received. The DUS gives this provisional advance certification on the Provisional Major Completion List (Provisional MC List). A Provisional MC List is sent to each DUS toward the middle of the spring term, containing the names for all seniors in the major who are finishing their degree requirements in that term.

On the Provisional MC List the DUS is asked to supply the appropriate designation for each student enrolled in the major:

- The student has met all the requirements of the major, including the senior requirement, and is clear for graduation. This designation does not often apply.
- The student will have met all of the requirements of the major, including the senior requirement, if and when he or she successfully completes all of the courses in the major in which he or she is enrolled.
- The student will have met all of the requirements of the major if and when he or she successfully completes all of the courses in which he or she is enrolled.
- There is no way the student can meet all of the requirements of the major at the conclusion of the term.

In addition to the Provisional MC List, the DUS is asked to complete a Major Completion form (see Appendix F) for each student. On this form, which shows all of the courses in which the student is enrolled, the DUS will be asked to indicate the specific courses that the student needs to complete in order to graduate. If the student needs only one of several courses, the DUS should indicate that as well. That way the Registrar's Office can clear a student for graduation as soon as grades in the specific required courses have been recorded.

To aid the DUS in keeping track of the courses that their majors have completed, the Registrar supplies the DUS with copies of the academic records of each junior and senior in the major. The academic records of students are forwarded to the DUS twice yearly: once in August, showing courses completed through the previous spring term, and again in late March in conjunction with the Provisional MC List, showing courses completed through the previous fall term, as well as courses in the current spring term in which the student is enrolled. The DUS uses these forms to verify the progress of each student in the major and discusses the options available to each student during course registration approval meetings at the start of each semester. In addition, the DUS also reviews each student's record to ensure that prerequisite courses (prerequisites for the major as well as prerequisites for more advanced courses) are being taken at the correct time so that the student is on track to complete the major in eight semesters. If the prerequisite requirements are not being met, the DUS works with the particular student to structure a course plan that meets all of the program's requirements.

Another task for the DUS, immediately after the Spring term grades for seniors become available, is the identification of seniors warranting "Distinction in the Major." The criteria for this honor are set by Yale College regulations: a student must earn grades of A or A- in three-quarters of the courses required by the major and a grade of A or A- for the senior requirement. For Distinction in the B.S. degree in Mechanical Engineering, only required courses (including electives), but not prerequisites, are considered.

After the student is cleared for graduation with the B.S in Mechanical Engineering by the Registrar (having been previously reviewed and approved by the DUS), the transcript of the student receives the designation, "Has completed an ABET-accredited program in Mechanical Engineering."

C. Transfer Students and Transfer Courses

Yale College welcomes a small number of transfer students (typically between 20 and 30) each year. (See Table 1-3 below.) There have not been any transfer students that were Mechanical Engineering majors in the past five years. Transfer students enter either the sophomore or junior year, and must enroll at Yale for a minimum of two years (four terms) to qualify for a bachelor's degree. Students may transfer from fully accredited two- or four-year institutions.

Table 1-3. Number of transfer students enrolled in Yale College.

Academic Year	Number of Transfer Students Enrolled	Number of SEAS Majors
2015–2016	24	0
2016–2017	24	0
2017–2018	26	1 (Chemical Engineering)
2018–2019	16	1 (Environmental Engineering)
2019–2020	21	1 (Chemical Engineering)

As competitive as the admissions process is for first-year students, the transfer process is even more so. Yale receives more than 1,000 transfer applications each year and has spaces for only 20 to 30 students. While GPA is not the only factor that the admissions committee takes into consideration, it may be helpful to note that the average college GPA of admitted transfer candidates is 3.9.

The Admissions Committee meets once each year in the spring to consider all transfer candidates for the coming academic year. The transfer application deadline is March 1. Candidates will be notified of their admissions decisions by mid-May.

The following regulations apply to students admitted to Yale College by transfer from other institutions:

1. In order to graduate from Yale College, transfer students must fulfill all the requirements for the bachelor's degree. They must thus earn a total of the equivalent of at least thirty-six course credits, where the total consists of the sum of the credits awarded to them for their work at their previous institutions with course credits subsequently earned at Yale.

   They must also complete the requirements of a major program in Yale College and fulfill the distributional requirements for the bachelor's degree, which includes the foreign language requirement.

   Upon their arrival at Yale, transfer students consult carefully with their Residential College Deans to ascertain their status with regard to the distributional requirements, especially the foreign language requirement. The Yale Admissions staff works closely with the DUS to determine how many of the courses at the student's previous institution will count toward the intended major program at Yale. This process (which is similar to that described below for determining Transfer Credit for a Yale College student) includes a comparison of the syllabus, assignments, exams, and content of the course at the previous institution and the comparable course at Yale, and the transfer student's performance in the course at the previous institution.

2. Transfer students are expected to enroll in Yale College for the number of terms designated at the time of the final credit evaluation made of their work at previous institutions. Under no circumstances may a transfer student complete fewer than four terms of enrollment in Yale College. Under no circumstances may a transfer student earn fewer than eighteen course credits at Yale or accelerate by use of acceleration credits.

3. A preliminary evaluation of transferable credits is made at the time of the student's admission. Final evaluation of transfer credits is completed when all official transcripts from a student's previous institutions have been received.

4. A transfer student's Yale transcript indicates the institution from which the student transferred to Yale, and the number of course credits earned there. It does not list the titles of courses taken or grades earned at the transfer student's previous college or university.

5. Transfer students may receive course credit for work completed outside Yale only for studies completed before matriculation at Yale; transfer students may not receive course credit for any outside courses taken after they have enrolled in Yale College.

Regarding Transfer Courses, credit transfer is evaluated both by Yale College with respect to Yale's graduation requirements and by the Mechanical Engineering DUS with respect to Program requirements. With respect to the review of credit transfer by Yale College, a student may apply as many as two course credits earned at another college or university toward the 36-course-credit requirement for graduation from Yale College. Courses in the Yale Summer

Programs are not considered outside courses, and there is no limit on the number of such courses that a student may offer toward the requirements of the bachelor's degree. Credits earned outside Yale may not be used to reduce the expected number of terms of enrollment in Yale College.

For credit to be given for courses taken elsewhere, all of the following conditions must be met:

1. The Director of Undergraduate Studies in the subject of a course taken elsewhere must approve the award of credit at Yale for the course.

2. A student who has studied at an American university, or abroad, in a program sponsored by an American university, must provide the office of the Residential College Dean with an official transcript of the work completed. A student who has enrolled at a foreign university should supply an official transcript if the university issues transcripts; if it does not, the student must furnish an official certificate of enrollment, showing the course or courses completed.

3. Students seeking outside credit should be prepared to furnish a copy of the course syllabus, as well as essays and examinations written in the course. In some cases, a letter from the instructor of the course may be required, or the student may be asked to pass an examination on the material of the course. Such information may be particularly necessary in the case of study at a foreign university.

4. Study undertaken in the United States must be at a four-year accredited institution that grants a bachelor's degree in the arts and sciences. Foreign study must be completed at a university or other approved institution. Credit may be awarded only for work done while a student was officially enrolled at such an institution, and cannot be given for any work completed independently of such formal enrollment.

5. A grade of A or B is expected; a grade of C is acceptable. Credit cannot be given for a course in which a grade of D was earned. Credit also cannot be given for a mark of Credit on a Credit/D/Fail option, nor for a grade of Pass on a Pass/Fail option, if the student had the choice of taking the course for a letter grade.

6. In order for credit to be given for a course completed at another university, the course must carry a value of at least three semester credit hours; if the course is taken at an institution on the quarter system, it must carry a value of at least four-and-one-half quarter units.

7. In order for credit to be given for a course completed at another university, the number of contact hours for the course must equal or exceed the number of contact hours for an equivalent course offered in Yale College during the fall or spring term, and the length of term (from the first to the last day of classes) must be at least four consecutive weeks.

D. Advising and Career Guidance

Several kinds of advisers help undergraduates plan their academic program at Yale. The First-

Year Faculty Adviser, who approves first-year student schedules, is assigned by the Residential College Dean, as is the First-Year Counselor. The responsibility for seeking out these people and making use of their experience and advice is chiefly that of the student. Students can also obtain advice from Directors of Undergraduate Studies; indeed, after a student has declared his or her major, the Director of Undergraduate Studies for that major is one of the two main sources of academic advising for the student (the other being the Residential College Dean). These advisers are now discussed in the order in which students generally encounter them.

The **Residential College Dean** plays a central role in undergraduates' academic careers. As the representative of the Yale College Dean's Office in the residential college, the dean administers the academic regulations and oversees First-Year Counseling and Faculty Advising. The dean also counsels students on personal and academic matters, and gives advice about the rules of Yale College. The residential college dean's office maintains students' academic records. If a student should have a problem with a particular course, the dean can often help resolve it by discussing the problem with the instructor or the Director of Undergraduate Studies of the department offering the course, or by referring the student to the tutoring program administered by the Yale College Dean's Office. For these reasons and others, the dean is crucial to academic life at Yale. The dean's advice can be invaluable not just in this first year, but throughout a student's whole career at Yale.

The **First-Year Counselor** is a senior who lives with first-year students and serves as a source of information and assistance throughout the year, especially in the early weeks of the fall term. A small number of students are assigned to each First-Year Counselor, who gives suggestions about curricular and extracurricular options and is readily available to take an interest in students' academic or personal concerns. Since First-Year Counselors are seniors, they can often give firsthand advice on how best to use the facilities, both academic and social, of the residential colleges and of Yale College.

A fellow of a residential college, either a member of the faculty or a fellow knowledgeable about education in Yale College, acts as the **First-Year Faculty Adviser**. During the course selection period, first-year students meet with their advisers both to discuss the broad outline of their academic career and to approve the specific courses they choose for the year. With a few telephone calls, e-mails, or referrals to the appropriate people, the adviser can often resolve special questions about particular courses or placement. No First-Year Faculty Adviser can be expected to know everything about the curriculum, but any adviser can put a student in touch with someone who can answer a question that he or she cannot. And as a faculty contact, the adviser can also help throughout the school year with educational plans. Since the faculty adviser does not live in the college, as do the First-Year Counselors and the Residential College Dean, students need to go to the faculty adviser’s office after making an appointment.

Students are encouraged to discuss with their First-Year Faculty Adviser not only their choices of particular courses, but also the relative merits of various options in the Yale curriculum. The signature of the faculty adviser on course schedules, which is required for registration, comes after a careful discussion of the student's course of study.

The undergraduate program of each department is under the general supervision of a **Director of Undergraduate Studies (DUS)**, who is in charge of the undergraduate curriculum of each department or program. Directors of Undergraduate Studies are authorities on the nature and objectives of their disciplines and the general features of the departments' undergraduate programs. In particular, the DUS is familiar with the range, focus, and objectives of individual courses in the department, as well as with departmental placement policies and major requirements. If a faculty adviser cannot answer a student's question about a particular department and the student is unable to find the answer in the Yale College Programs of Study (YCPS), then the student should consult the appropriate DUS. The name and contact information of each department's DUS is listed at the start of each departmental entry in the YCPS, which is available at catalog.yale.edu/ycps.

In the Department of Mechanical Engineering & Materials Science, the MEMS DUS maintains a message and email listserv for all Mechanical Engineering majors and first- and second-year students interested in majoring in Mechanical Engineering. In September of each academic year, the MEMS DUS receives a list of first-year Yale College students that have indicated an interest in the Mechanical Engineering major either in their application to Yale College or at the SEAS Open House, and these students are added to the Mechanical Engineering message and email listserv. Using this listserv, the DUS posts messages about new courses in the curriculum, career options, research opportunities, and extra-curricular activities.

The MEMS DUS also serves as the sophomore, junior, and senior advisors for all prospective and declared mechanical engineering majors. The DUS meets with each advisee at least once per semester, and must approve and sign the course selection form each semester for each advisee, which allows students to register for their courses. The DUS is available for additional meetings, especially with juniors and seniors, to discuss research and internship opportunities, graduate school, and possible career paths. The Yale College web portal (https://advising.yalecollege.yale.edu/advisers) provides numerous resources for advising and mentoring for the Directors of Undergraduate Studies and course instructors. The portal provides guidance to advisers and secure access to student records.

During the exit interview for seniors, the DUS discusses the positive aspects of the Mechanical Engineering Program, any aspects that need improvement, and the steps required for registration and licensure as a Professional Engineer. It is noted that SEAS pays the costs for the licensure examination and study materials for senior ME majors (even after graduation).

In addition, students often seek advice about academic matters, internship and research opportunities, student life, study abroad, and post-graduation options from other offices on campus. Staff at the University Libraries, the Yale College Dean's Office, and the cultural centers are ready to support students in a variety of endeavors. There are four cultural centers at Yale: the Afro-American Cultural Center, the Asian American Cultural Center, La Casa Cultural de Julia de Burgos (the Latino Cultural Center), and the Native American Cultural Center. Students can also obtain advice on a range of matters from the staff at the Center for International and Professional Experience (CIPE), an umbrella organization whose constituent offices are Study Abroad, Fellowship Programs, the Office of Career Strategy (including the Health Professions Advisory Program), and Yale Summer Session. Out of these offices, the

Office of Career Strategy deserves a more in-depth discussion, since it is used frequently by undergraduates.

The **Office of Career Strategy (OCS)** offers career counseling, professional school advising, employment and internship opportunities, and career development resources. The Yale OCS works with undergraduates and alumni to clarify career aspirations, identify employment and educational opportunities, and offer counseling and support at every stage of career development. Students can walk in with questions or schedule an appointment with an advisor. David Halek is the Director of Employer Relations of OCS, who oversees the team that manages relationships with corporate recruiters interested in students pursuing engineering careers. As an example of one of his initiatives, Mr. Halek organizes a series of discipline-based networking events where students interact with visiting professionals and pursue employment opportunities. The team also hosts an Engineering Career Fair Collaborative each fall for students of Yale, MIT, Harvard, Olin College of Engineering, Boston University, and Tufts.

Another initiative within OCS is STEMConnect, which supports Yale students who are interested in a wide range of careers related to science research, technology, engineering, and data science/statistics. Its mission is to connect students to abundant advising resources, alumni for networking opportunities, events to learn more about employers, and workshops to broaden students' understanding of the job search. Laurie Coppola is the Senior Associate Director for STEMConnect and Health Professions. As an example, in the Spring 2020 semester, Ms. Coppola and the STEMConnect team collaborated with SEAS student groups and assisted with the Deputy Dean's 2020 SEAS Summer Fellowship Program to counter the sudden loss of summer internship and research opportunities due to the COVID-19 pandemic. To help with the funding of this fellowship, students were encouraged to apply to the OCS Domestic Summer Award (DSA). Nearly 60 students participated in the fellowship in Summer 2020, and a large subset of those were funded by the DSA.

Furthermore, the SEAS **Center for Engineering Innovation and Design (CEID)** partners with OCS to host career events. In the Academic Year 2019–2020, they hosted monthly tech-talks and recruiting events. The CEID also hosts presentations and seminars for undergraduates related to career options, research topics, and pressing engineering problems including energy production, space transportation, and biomedical device design. A list of lectures and seminars hosted by the CEID in the Academic Year 2019–2020 is provided in Appendix E.

The CEID also hosts a summer fellowship program to help students pursue their engineering and design ideas. The program runs for 10 weeks each summer as a product development workshop where student teams (typically 4 teams of 3 students) pursue their own design interests having all CEID resources (including the full-time staff) at their disposal. The fellowship allows students a unique opportunity to focus on their own project to advance a concept into a potential product. In addition to increasing design skills, some of the projects have advanced to become the basis of startup companies.

The **Tsai Center for Innovative Thinking at Yale (Tsai CITY)** serves students from across Yale's campus through programs, funding, and mentorship. Tsai CITY programs offer diverse entry points to innovation and entrepreneurship, from drop-in sessions to multi-week, application-only programs. Engineering students can learn business fundamentals through workshops on entrepreneurship, design thinking, and fundraising. They can learn and apply skills in intensive project-based workshop series in topics as diverse as app design, clinical innovation, climate change mitigation, and food innovation. Students can also become connected to other students with ideas to form teams and companies tackling a variety of problems via pitch events and networking hosted by Tsai CITY. For ventures and projects that are more developed, Tsai CITY has cohort-based accelerator and incubator programs during the semester and summer to provide funding, mentorship, and resources to help launch these projects. Finally, teams also have the opportunity to apply for grant funding, prize money, and investment through Yale and Tsai CITY.

E. Work in Lieu of Courses

Yale does not award credit for work in lieu of courses.

F. "Acceleration Credit" for Prior Academic Work

In certain subject areas, Yale College students can earn "acceleration credits" for prior academic work, as evidenced either by sufficiently high scores on Advanced Placement (AP) exams or by earning a B or higher in advanced courses taken during the first year without having taken prerequisites. In the Mechanical Engineering Program, it is possible for students to receive acceleration credit for courses in mathematics only. It is also possible for students to satisfy the chemistry prerequisite with a sufficiently high AP score, although acceleration credit is not officially awarded in this case. (In any subject, a score of 7 on International Baccalaureate (IB) higher-level exams, or A in A-levels, is treated as being equivalent to a 5 on the corresponding AP exam.) Further details regarding prerequisite course requirements in mathematics and chemistry for the Mechanical Engineering Program are provided below.

The goal of the mathematics prerequisites for the Mechanical Engineering Program is to bring students to proficiency in multivariable calculus (ENAS 151 or MATH 120). Students with significant preparation in mathematics prior to entering Yale may not need to take all of the mathematics prerequisites: Calculus of Functions of One Variable I (MATH 112), Calculus of Functions of One Variable II (MATH 115), and Multivariable Calculus for Engineers (ENAS 151) or Calculus of Functions of Several Variables (MATH 120). As soon as students arrive on campus in their first year, they can begin discussing the appropriate first mathematics course to take at Yale with the DUS in Mathematics and the DUS in Mechanical Engineering. The Mathematics Placement Exam, which is offered online prior to the start of the fall term, is required of every student before their first calculus course with a MATH course number (e.g., MATH 112, MATH 115, or MATH 120). In terms of mathematics course placement, MATH 120 and ENAS 151 are treated as the same, since there is not a separate placement exam for ENAS 151.

With regard to acceleration credit in mathematics, the following scenarios are relevant for Mechanical Engineering students. A student receives one acceleration credit by either: (1) placing into and taking MATH 115; or (2) scoring a 5 on the AP Calculus AB exam or a 4 on the

AP Calculus BC exam. A student receives a total of two acceleration credits by either: (1) placing into and taking MATH 120; or (2) scoring a 5 on the Calculus BC exam. A student who has not received any acceleration credits associated with high AP exam scores and whose first calculus course at Yale is ENAS 151 receives no acceleration credits. It should also be noted that high performance on the Mathematics Placement Exam, by itself, does not yield any acceleration credit. When a student receives acceleration credit in mathematics, this fact is stated on the student's official transcript, but it is not tied to a specific MATH course number.

In terms of fulfilling the mathematics prerequisites for the Mechanical Engineering major, a student who passes an advanced prerequisite is automatically considered to have demonstrated proficiency in the lower-level prerequisites. Therefore, a student whose first calculus course at Yale is MATH 115, and who receives a passing grade in that course, is considered to have demonstrated proficiency in MATH 112. A student whose first calculus course at Yale is multivariable calculus (ENAS 151 or MATH 120), and who receives a passing grade in that course, is considered to have demonstrated proficiency in both MATH 112 and MATH 115. Occasionally a student may have sufficient preparation prior to entering Yale such that the DUS recommends the student to take ENAS 194 (Ordinary and Partial Differential Equations with Applications), which is a required course for the major, not a prerequisite. Upon receiving a passing grade in ENAS 194 (for which ENAS 151 is a prerequisite), such a student is automatically considered to have demonstrated proficiency in all three mathematics prerequisites (MATH 112, MATH 115, and ENAS 151 or MATH 120).

The goal of the chemistry requirement for the Mechanical Engineering Program is to bring students to proficiency in one semester of chemistry (CHEM 161 or higher). Yale does not award acceleration credit for high scores on the AP Chemistry exam. However, Mechanical Engineering students with sufficient chemistry experience can satisfy the chemistry requirement via a 4 or 5 on the AP Chemistry exam (or a 7 on the IB Chemistry exam or an A in A-Level Chemistry course). In this case, fulfillment of the chemistry requirement is tracked by the DUS via official copies of the relevant exam scores of the student. Alternatively, students may satisfy the chemistry requirement by completing an appropriate introductory chemistry course at another university, subject to approval from the DUS of Chemistry. (See Section C, Transfer Students and Transfer Courses.) In this case, the course is added to the student's transcript with the notation "credit toward major requirements only."

G. Graduation Requirements

A student must complete 36 term courses or their equivalent in Yale College. In doing so, the student must fulfill the distributional requirements of Yale College and the requirements of a major program. These requirements are clearly stated in the Yale College Programs of Study.

B.S. degree program in Mechanical Engineering: This is the most technically intensive mechanical engineering degree program and is accredited by the Engineering Accreditation Commission of ABET, Inc. This program is appropriate for students who plan careers as practicing engineers in industry, consulting firms, or government, as well as for students who are considering a career in research and plan to pursue an advanced degree in engineering. Here we list the requirements for the B.S. degree in Mechanical Engineering for the Class of 2020. (Note that the requirements for the B.S. degree in Mechanical Engineering for the Class of 2021 and beyond have changed and will be described in detail in Chapter 4.)

The prerequisites in mathematics are MATH 112, 115, and ENAS 151, or the equivalent. The basic science prerequisites are PHYS 200, 201, or 180, 181; one laboratory from PHYS 165L or 205L, and one from PHYS 166L or 206L, or equivalents. The chemistry prerequisite is one term course in chemistry numbered CHEM 161 or higher.

Nineteen term courses beyond the prerequisites are required as follows:

1. Advanced mathematics: ENAS 194 and MATH 222 or 225.
2. Mechanical engineering and related: MENG 211, 280, 285, 286L (half credit), 361, 363L, 383, 389, 390, 487L (half credit – part of senior requirement), 488L (half credit – rest of senior requirement), ENAS 130, and EENG 200.
3. Technical electives: Four approved technical electives chosen in consultation with the Director of Undergraduate Studies.

The curriculum in this program is arranged in prescribed patterns, but some departures from it are possible with approval of the Director of Undergraduate Studies.

Senior requirement Students must successfully complete a year-long team-based design project (via MENG 487L and MENG 488L) during their senior year.

H. Transcripts of Recent Graduates

Transcripts of recent Program graduates are available for viewing and will be forwarded separately to the ABET Team Chair. The transcripts of the program graduates state that the student received the B.S. degree in Mechanical Engineering and the designation "Has completed an ABET-accredited program in Mechanical Engineering."

CRITERION 2. PROGRAM EDUCATIONAL OBJECTIVES

A. Mission Statement

Yale University, established in 1701, is one of the premier centers of higher education in the world. The University offers both undergraduate and graduate degrees in a tremendous diversity of fields. At the heart of the educational process is the mission of the University, as stated on the University website (www.yale.edu/about-yale/mission-statement):

> Yale is committed to improving the world today and for future generations through outstanding research and scholarship, education, preservation, and practice. Yale educates aspiring leaders worldwide who serve all sectors of society. We carry out this mission through the free exchange of ideas in an ethical, interdependent, and diverse community of faculty, staff, students, and alumni.

The mission statement of Yale College (the undergraduate portion of the University) appears in the Yale College Programs of Study (YCPS) and is located at catalog.yale.edu/ycps/mission-statement:

> The mission of Yale College is to seek exceptionally promising students of all backgrounds from across the nation and around the world and to educate them, through mental discipline and social experience, to develop their intellectual, moral, civic, and creative capacities to the fullest. The aim of this education is the cultivation of citizens with a rich awareness of our heritage to lead and serve in every sphere of human activity.

B. Program Educational Objectives

Engineering at Yale was established in 1852. SEAS is composed of six departmental units (Applied Physics, Biomedical Engineering, Chemical & Environmental Engineering, Computer Science, Electrical Engineering, and Mechanical Engineering & Materials Science). The Department of Mechanical Engineering & Materials Science (MEMS) has formulated a mission statement for the Mechanical Engineering Program and a set of educational objectives to achieve this mission.

The educational mission of the Mechanical Engineering Program is to provide an excellent education, within one of the finest liberal arts universities in the nation, so that our students are prepared to become the next generation of Mechanical Engineers. Our students will have the ability to pursue graduate studies in Mechanical Engineering and pursue job opportunities as Mechanical Engineers in industry, government, and other sectors.

The following five Program Educational Objectives (PEOs) have been established for the Mechanical Engineering Program:

PEO 1: To provide a comprehensive introduction to the basic science and mathematics courses that provides the foundation of mechanical engineering.

PEO 2: To provide thorough training in methods of analytical, experimental, and data analysis, including problem formulation.

PEO 3: To provide the fundamentals of the design process including project innovation, synthesis, and management both individually and in a team setting.

PEO 4: To provide both technical and nontechnical programs that develop strong oral and written communication skills.

PEO 5: To instill in our students an understanding of their professional and ethical responsibilities that impact society and their profession.

These Program Educational Objectives are published in the Yale College Programs of Study (YCPS) as well as online at http://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study.

C. Consistency of the Program Educational Objectives with the Mission of the Institution

Yale's institutional mission is to promote scholarship through a strong liberal arts education with the goal of sustaining and improving society. The more specific mission of the Mechanical Engineering Program is to prepare students to become the next generation of Mechanical Engineers. We believe that training Mechanical Engineers within the context of a liberal arts education is an ideal setting and consistent with our Program Educational Objectives.

Engineering education and training at Yale has two distinctive features. First, engineering students live and interact in residential colleges with classmates who have many different academic pursuits and a range of technical backgrounds. Second, engineering students are required by Yale College to take a significant number of courses in humanities, social sciences, writing, and languages. This exposure to a variety of people, academic disciplines, and perspectives allows our students to understand that the grand engineering challenges that face society today involve scientific and technical components, as well as complex political, economic, and ethical issues.

Knowledge of the non-technical aspects will be necessary to solve the most important engineering challenges facing society in the 21st century, such as understanding climate change, battling global pandemics, and developing new and sustainable energy sources. Furthermore, engineering solutions will be most effective when they are clearly communicated to the general public. Thus, in addition to the science, mathematics, engineering, and design courses, the Program provides training for the students in oral and written communication skills and in identifying the impacts of engineering solutions on society. Thus, the Program Educational Objectives are consistent with both the institutional and program missions.

D. Program Constituencies

The Mechanical Engineering Program has identified four constituencies: Students, Faculty, Employers/Recruiters, and Alumni.

Students are the main focus of the Mechanical Engineering Program. Students need to acquire a scientific knowledge base, mathematics and computational abilities, engineering design experience, and a laboratory skill set that will allow them to excel professionally. In addition, effective communication skills and knowledge of the wide impact of engineering solutions are crucial for a wide spectrum of careers in academia, industry, and government. The Program also seeks to expose students to the many subfields of Mechanical Engineering, myriad career opportunities, and graduate programs so that they can effectively choose their career path.

Mechanical Engineering students use their summers to gain experience in their field and to "try out" different research areas or career paths before they graduate. During the summers after their first and second years, nearly 75% of Mechanical Engineering majors serve as research assistants at Yale, through Yale's Dean's Fellowship and Summer Undergraduate Research Fellowship programs, as well as at other universities through the National Science Foundation's Research Experiences for Undergraduates program. By contrast, during the summer after their third year, usually more than 75% of Mechanical Engineering majors carry out internships, and many of the internships lead to full-time positions after graduation. For example, the 17 Mechanical Engineering majors of the Class of 2020 spent their summer of 2019 as follows:

- 12 out of 17 carried out internships at engineering firms and tech companies (Landsdowne Labs, Pratt & Whitney, Lockheed Martin, Shell, Merck, Huntington Ingalls, Siemens, ASML, BorgWarner, and WiTricity);
- 1 out of 17 carried out an internship at an investment firm (Avascent Group);
- 2 out of 17 attended summer school;
- 2 out of 17 served as research assistants at Yale; and
- 1 out of 17 volunteered at The Good Samaritan.

After completing their degrees, Mechanical Engineering majors move on to a variety of postgraduate pursuits. As discussed in more detail below, recent graduates have undertaken graduate studies in science and engineering, jobs with consulting and financial services firms, and engineering positions in the aerospace, software, energy, automotive, and biotech industries.

At the top of the next page, Table 2-1 shows the career paths of the 17 graduates of the Mechanical Engineering Program's Class of 2020. Three are pursuing graduate studies in Mechanical Engineering; 10 have taken engineering positions, 2 have taken business analyst positions at consulting firms, and 2 are still looking for full-time engineering positions. It is clear that Students 3, 5, and 10 took job offers from companies for which they had interned during the summer after their third year. Some additional students also had offers that they chose not to pursue (e.g., because of attending graduate school or accepting another job offer) from companies at which they had previously interned.

Table 2-1. Post-graduation career paths of the Mechanical Engineering Program's Class of 2020.

Student Identification	Career Path
1	Graduate school in Mechanical Engineering
2	Engineer at EDP Renewables
3	Engineer at Siemens (will graduate in Dec. 2020)
4	Engineer at HBK Engineering
5	Engineer at Lockheed Martin
6	GE Aviation Edison Program; pursuing Master's in Mechanical Engineering
7	Graduate school in Mechanical Engineering at Purdue University
8	Graduate school in Mechanical Engineering at MIT
9	Business analyst at McKinsey & Company
10	Engineer at Huntington Ingalls
11	Engineer at Veolia North America
12	Engineer at General Motors
13	Navy engineer at Naval Reactors Headquarters
14	Engineer at McMaster-Carr
15	Currently looking for an engineering position
16	Currently looking for an engineering position
17	Analyst at CMA Strategy Consulting

For information about previous class years, the Yale Office of Career Strategy (OCS) maintains a database of information in accordance with guidelines set by the National Association of Colleges and Employers. This database, known as the Yale College Outcomes database, contains information mainly on what graduates do after leaving Yale. In exchange for submitting data to the database, students obtain post-graduation access to OCS's resources, so the submission rate is quite high. OCS collects outcomes information from students by major over each summer while they are undergraduates, then six months after graduation, and finally four years after graduation. The information is collected through direct surveys and supplemented through publicly available information (such as LinkedIn).

OCS has recently implemented an interactive online tool that allows anyone to search the Yale College Outcomes database by year and major. Because information about post-graduation plans is not available until six months after graduation, the most recent class year for which data are available is 2019; the oldest data in the database are from 2016. Information for Mechanical Engineering Program graduates can be accessed at https://ocs.yale.edu/outcomes/yale-college-outcomes#!Mechanical%20Engineering.

Results for the available data (2016–2019) indicate that within six months after graduation, 64% of Mechanical Engineering Program graduates take on full-time jobs, 16% attend graduate or professional school, 9% serve in the military, and the remaining students pursue other paths such as service programs (e.g., Teach for America) or entrepreneurial ventures. More than half (57%) of those working full-time are in engineering positions, 10% are in the finance sector, and the remaining graduates end up in other areas such as consulting, software development, and project management. Three-fourths of those attending graduate or professional school are in Ph.D. programs, with the remaining one-fourth equally split between M.S., M.A., and other degrees.

Given the large percentage of Mechanical Engineering graduates who end up in technical fields (engineering, software development, etc.), it is clear that the ME Program is succeeding in achieving its PEOs 1 and 2. The database does not allow the user to filter based on whether students' post-graduation plans involve design or not, but it is highly likely that the students heading for engineering positions will employ some or all aspects of their design training in their jobs. Certainly any graduate working for a large employer must be able to perform as a member of a team, and it should be noted that out of those graduates who pursue full-time jobs, 76% of them are working for employers having more than 250 employees. Therefore, the ME Program is clearly meeting PEO 3. Moreover, students heading to industry, finance, project management, graduate school, entrepreneurial ventures, military service, and so on must be adept at oral and written communication (PEO 4). The only Program Educational Objective that cannot be directly linked to data in the database is PEO 5. Nevertheless, it is clear that the Yale ME experience prepares its students well for a range of post-graduate pursuits.

Our **faculty members** strive to maintain the high quality of our Mechanical Engineering Program. Each faculty member teaches one or two undergraduate courses per year and expects that students will be properly prepared for the courses in which they are enrolled. Faculty members also mentor students in undergraduate research during the academic year and throughout the summer and serve as advisers for students in Special Projects I and II (MENG 471, 472, 473, and 474). Faculty members want their advisees to possess the required science and mathematics knowledge and engineering design skills to be able to perform research projects in their laboratories. Our faculty members also conduct world-class research and contribute to their professional communities. They share their experience, insight, and research activities with undergraduates, which help prepare them for successful careers in industry or graduate school. In addition, our faculty recognize that successful Mechanical Engineering graduates reflect well on the Program and will draw new talented undergraduate and graduate students into the Program.

Potential employers and recruiters want to attract talented Mechanical Engineering students as summer interns and as permanent employees. In addition, directors of summer research programs, such as the National Science Foundation's Research Experiences for Undergraduates program, and Graduate School Admissions Committees seek our students for their programs. This constituency needs students with sufficient training in science and mathematics, engineering design experience, laboratory and computational skills. Furthermore, employers and recruiters seek students that can communicate clearly and work synergistically on a team. The top employers for recent Yale graduates from the Mechanical Engineering Program are: Arconic, Buro Happold, and Boeing, as well as the United States Air Force and Navy through Yale's Reserve Officers' Training Corps program. (See https://rotc.yale.edu.)

Alumni want our Mechanical Engineering Program to educate, train, and graduate successful Mechanical Engineers that fulfill our Program Educational Objectives to enhance the professional value of the Yale Mechanical Engineering degree. An important alumni stakeholder is the Yale Science and Engineering Association (YSEA). Founded in 1914, YSEA is one of the oldest university alumni organizations in the world with a focus on issues in science, technology, engineering, and mathematics. Its mission is to connect alumni with students, the University, and other alumni to strengthen the Yale science and engineering community. YSEA aims to strengthen Yale's education of leaders for a world increasingly dominated by science and technology. They do so in several ways: by encouraging interaction between Yale and its engineering and science alumni; by recognizing and publicizing the accomplishments of Yale students, faculty and distinguished alumni with special awards and prizes; by assisting students financially with research grants, prizes, and scholarships; and by making strategic investments to enable or complement Yale initiatives that advance science and engineering.

In addition, Yale SEAS actively engages with SEAS alumni through its Director of Communications, Steven Geringer. In the last calendar year, more than 150 news stories have been posted to the School's news page, of which more than 100 were written by the School's communications team. These include research accomplishments, faculty and student profiles, student group activities, and highlights of faculty and student awards and honors. Higher-profile stories are also posted on the University's news site, YaleNews, and further disseminated and published in worldwide publications including The New York Times, Boston Globe, The Guardian, National Geographic, and Wired. Stories of particular relevance are also shared with key alumni in partnership with Yale's Office of Development. Additionally, news stories are frequently repurposed and shared on the School's social media accounts (3,300+ Facebook followers; 2,500+ Twitter followers). The School's annual magazine, Yale Engineering, publishes larger, in-depth feature stories focused on research and teaching within the School. The publication is digitally distributed to more than 14,000 subscribers, the majority who are SEAS alumni. An additional 2,000 printed copies are distributed to current and prospective students, peer institutions, and School partners.

E. Process for Review of the Program Educational Objectives

The Department of Mechanical Engineering & Materials Science employs a multi-pronged approach to evaluate our Program Educational Objectives and ensures that all four constituencies are involved in the evaluation. A schematic of the process is shown in Figure 2-1 at the top of the next page.

As can be seen from the figure, the first step is the collection of data from each of our four constituencies. Our **students** provide feedback on our PEOs using the methods below (the frequency of evaluation is indicated in parentheses):

1. Course selection and approval meetings with DUS (at least once each semester).
2. Web-based course feedback via Canvas (continuous).
3. End-of-term course evaluations (each semester).
4. Personal discussions with DUS (as needed).
5. Exit interviews conducted by DUS (yearly).

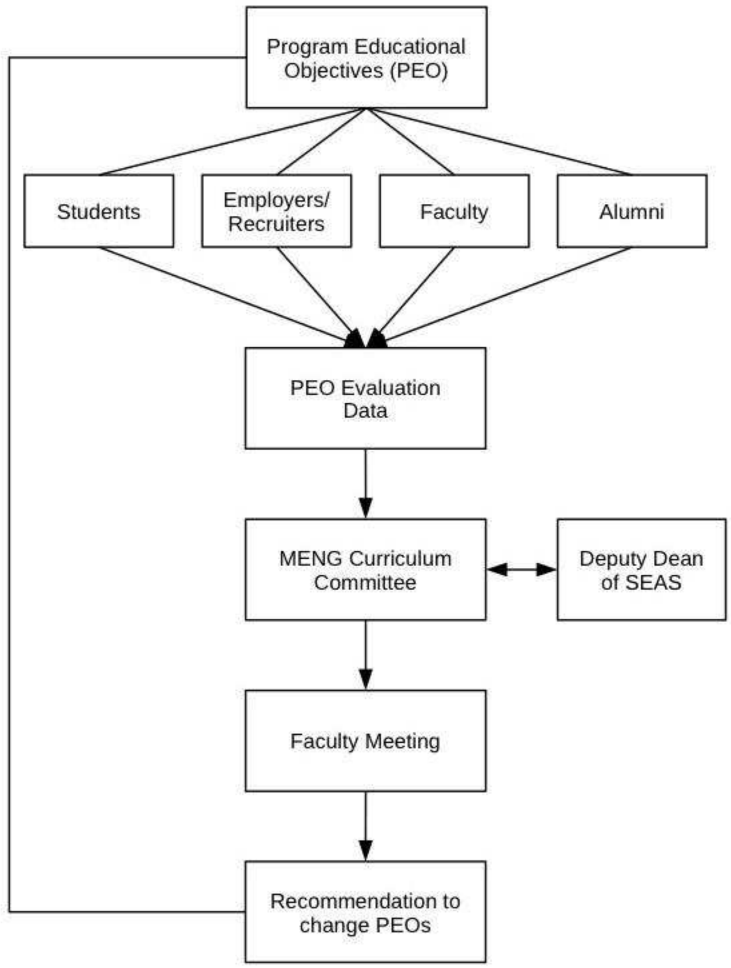


Figure 2-1. Schematic of the Process to Review, Evaluate, and Amend the Yale Mechanical Engineering Program Educational Objectives.

It is important for **faculty** to determine the fit of the PEOs with the educational and research directions of the Department of Mechanical Engineering & Materials Science. The faculty evaluate the PEOs using the following methods:

1. Faculty meetings (monthly).
2. MENG Curriculum Committee meetings (at least once each semester).
3. Personal discussions with DUS, Chair, or other faculty (as needed).
4. Discussions between the DUS and the Director of the Center for Engineering Innovation and Design (CEID) (as needed).
5. Discussions with faculty at peer institutions (as needed).

We also seek input from **employers, recruiters, directors of summer research programs, and other stakeholders** concerning the appropriateness and effectiveness of our PEOs. Our methods include direct discussions between the DUS, Director of the CEID, and the Dean of

SEAS, and potential employers. We track quantitative data concerning students that receive summer internships and research positions, graduate school acceptance, and job offers. Through meetings with all Mechanical Engineering majors each semester, the DUS tracks how each student spends his/her summers after their first, second, and third years, as well as their post-graduation plans. (Information about students' summer pursuits and post-graduation plans appeared at the start of Chapter 2.D.)

To collect input on the PEOs from **alumni**, we conduct surveys (biannually) and connect with SEAS alumni at YSEA and CEID events, graduation, and reunion events (yearly). In addition, the Dean of SEAS frequently meets with alumni and potential donors and conveys their thoughts on the PEOs to each DUS.

In the second step of the process for evaluating the PEOs, the DUS collects the data from all of the above sources and schedules a meeting of the MENG Curriculum Committee, which includes two tenured and two untenured faculty members from the Department of Mechanical Engineering and Materials Science. For the Academic Year 2019–2020, the Committee included the DUS and Profs. Eric Brown, Aaron Dollar, Rebecca Kramer-Bottiglio, and Marshall Long.

In the third step, the data are reviewed, debated, and interpreted by the Committee. The Committee can recommend changes to the existing objectives, including the addition or deletion of an objective to reflect changes in the program emphasis. The DUS then meets with the Deputy Dean of SEAS to ensure that any recommended changes in the PEOs are consistent with the larger mission of SEAS and the University. If any concerns are raised by the Deputy Dean, the Curriculum Committee continues its deliberations of the proposed changes to the PEOs until the concerns are mitigated. Recommendations of the Curriculum Committee along with supporting material are then presented and discussed at the next scheduled faculty meeting. After the initial presentation and discussion, a motion is made and seconded, and a final discussion takes place before the motion is put to a vote. If a modification to the PEOs is recommended, and it has passed the Departmental vote, revisions to the following Yale program guides are needed:

1. The Yale College Program of Study (YCPS) and its online version require revisions starting in mid-February.
2. The Guide to Undergraduate Studies in Engineering and Applied Science ("the Guide") copies and expands the YCPS material. Material for Guide updates is due in July.

Changes to (1) are made in the CourseLeaf web-content management system, and changes to (2) are made through the SEAS Director of Communications, Steven Geringer.

CRITERION 3. STUDENT OUTCOMES

A. Student Outcomes

The Yale University Department of Mechanical Engineering & Materials Science adopts the following Student Outcomes for the Mechanical Engineering Program:

SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

SO 3: An ability to communicate effectively with a range of audiences

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

This list of Student Outcomes can be found in the online version of the Yale College Programs of Study (YCPS) at http://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study.

B. Relationship of Student Outcomes to Program Educational Objectives

The curriculum (see Chapter 5) for the B.S. degree in Mechanical Engineering is designed to meet our program's five Program Educational Objectives (PEOs) as detailed in Chapter 2:

PEO 1: To provide a comprehensive introduction to the basic science and mathematics courses that provides the foundation of mechanical engineering.

PEO 2: To provide thorough training in methods of analytical, experimental and data analysis, including problem formulation.

PEO 3: To provide the fundamentals of the design process including project innovation, synthesis and management both individually and in a team setting.

PEO 4: To provide both technical and non-technical programs that develop oral and written communication skills.

PEO 5: To instill in our students an understanding of their professional and ethical responsibilities that impact society and their profession.

Table 3-1 below shows the relationship between our PEOs and Student Outcomes (SOs). This Table indicates that if students attain our Program's SOs, they will automatically fulfill our Program's PEOs.

Table 3-1. Relationship between Program Educational Objectives and Student Outcomes.

Student Outcomes→ Program Educational Objectives↓	1	2	3	4	5	6	7
1. To provide a comprehensive introduction to the basic science and mathematics courses that provides the foundation of mechanical engineering.	x						
2. To provide thorough training in methods of analytical, experimental and data analysis, including problem formulation.						x	x
3. To provide the fundamentals of the design process including project innovation, synthesis and management both individually and in a team setting.		x			x		
4. To provide both a technical and non-technical program that develop oral and written communication skills.			x				
5. To instill in our students an understanding of their professional and ethical responsibilities that impact society and their profession.				x			

C. Relationship of Curriculum to Student Outcomes

The following list identifies courses from the Mechanical Engineering curriculum (Chapter 5) that have demonstrable Performance Criteria in each of Student Outcomes 1–7. In this list, required courses are presented first, followed by elective courses. Each item in the list provides an example of an applicable performance criterion that is aligned with the stated SO.

Performance Criteria (PC) associated with each Student Outcome (SO)

SO 1:	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

Required Courses:

- ENAS 130: Ability to write code that solves an engineering problem using a simple numerical method.
- ENAS 194: Ability to apply mathematical methods to solve first- and second-order differential equations.
- EENG 200: Ability to analyze current flow through electronic circuits using differential equations.
- MATH 222: Ability to determine eigenvalues and eigenvectors of a matrix.
- MENG 211: Ability to analyze thermodynamics problems.
- MENG 280: Ability to apply mathematical concepts to structural analysis.
- MENG 285: Ability to use mathematics to characterize engineering materials.
- MENG 286L: Ability to use mathematics to analyze materials.
- MENG 361: Ability to use mathematics to study fluid flow.
- MENG 363L: Ability to apply mathematical principles of fluid mechanics and thermodynamics to laboratory experiments.
- MENG 383: Ability to use mathematics to describe rigid-body motion in two and three dimensions.
- MENG 389: Ability to use mathematics to analyze heat transfer problems.
- MENG 390: Ability to analyze control systems mathematically.
- MENG 487L: Ability to apply mathematics as needed to solve real engineering problems.
- MENG 488L: Ability to apply mathematics as needed to solve real engineering problems.

Electives:

- MENG 185: Ability to apply basic physics and math to engineering design problems.
- MENG 325: Ability to apply basic physics and math to design common machine elements (e.g., those associated with a drive train).
- MENG 365: Ability to apply conservation laws to energy conversion in propulsion systems.
- MENG 400: Ability to apply vector analysis for visualization (e.g., projections from 3D to 2D for graphics).
- MENG 404: Ability to apply basic physics and math to medical design problems.

- MENG 441: Ability to apply numerical methods to solve linear and nonlinear differential equations.
- MENG 459: Ability to mathematically abstract the dynamics of complex biomechanical systems into ordinary differential equation models.
- MENG 464: Ability to apply physics and math to solve problems relating to interatomic/intermolecular forces and surface properties.
- MENG 469: Ability to apply conservation laws to laminar flows.
- MENG 471: Ability to apply math and engineering to complete an independent project with emphasis on research or engineering design.
- MENG 472: Ability to apply math and engineering to complete an independent project with emphasis on research or engineering design.
- MENG 473: Ability to apply math and engineering to complete an independent project with emphasis on research or engineering design.
- MENG 474: Ability to apply math and engineering to complete an independent project with emphasis on research or engineering design.
- ENAS 118: Ability to apply basic physics and math to engineering design problems.
- ENAS 400: Ability to apply basic physics and math to engineering design problems.
- ENAS 778: Ability to apply math- and physics-based concepts associated with advanced robot design.
- BENG 350: Ability to apply chemistry, physics, and biology to human physiology.
- BENG 351: Ability to apply math, biology, and chemistry to create models of biological transport and reaction processes.
- BENG 353: Ability to solve the Navier-Stokes equation for steady pressure-driven flow in a cylindrical geometry.
- BENG 405: Ability to apply biology in order to understand the impact of biotechnology in the developing world from an engineering perspective.
- BENG 411: Ability to solve the Navier-Stokes equations in 2D and 3D geometries.
- BENG 434: Ability to calculate the Gibbs free energy of crystal nuclei.
- CENG 300: Ability to apply the 1^{st} and 2^{nd} Laws of Thermodynamics.
- CPSC 201: Ability to apply basic math to understand the theoretical foundations of computing (e.g., computability and complexity).
- CPSC 223: Ability to apply basic math to determine the computational efficiency of the main algorithms for sorting, searching, and hashing.
- CPSC 472: Ability to use math to understand dynamical systems.
- EENG 406: Ability to apply chemistry to connect material properties to aspects of solar cell design, processing, and performance.
- G&G 322: Ability to apply mathematical tools to solve problems relating to atmospheric science.
- G&G 342: Ability to apply basic physics to understand topics of contemporary interest, such as climate change.
- PHYS 301: Ability to apply the mathematical tools and techniques (in multivariable calculus, linear algebra, complex variables, vector calculus, and differential equations) needed for advanced undergraduate and beginning graduate study in the physical sciences.

- S&DS 220: Ability to apply basic math to recognize common abuses of statistical methods, such as a too-small sample size and incorrect interpretation of confidence intervals.
- S&DS 230: Ability to apply basic math to understand statistics concepts and data science topics.

SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Required Courses:

- EENG 200: Ability to design moderately sophisticated electronic circuits.
- MENG 390: Ability to analyze, design, and synthesize computer-controlled engineering systems with mechanical and electrical components.
- MENG 487L: Ability to design, construct, and test a functioning prototype engineering system to meet the needs of a real-world client.
- MENG 488L: Ability to design, construct, and test a functioning prototype engineering system to meet the needs of a real-world client.
- Yale College Distributional Requirements (electives in Humanities, Social Science, Writing, and Languages): Students learn non-technical subjects that can include courses in global affairs, cultural practices, social behavior, economics, and sustainability. See Chapter 5.

Electives:

- MENG 185: Ability to use CAD software to design 3D printed parts.
- MENG 325: Ability to design common machine elements, especially those associated with a drive train.
- MENG 400: Ability to use CAD tools to test and optimize a mechanical design.
- MENG 404: Ability to design novel solutions to clinical challenges posed by Yale School of Medicine clinicians and medical device company engineers.
- MENG 469: Ability to design airfoils using Mathematica and Javafoil.
- MENG 471: Ability to complete a design project under the supervision of a SEAS advisor.
- MENG 472: Ability to complete a design project under the supervision of a SEAS advisor.
- MENG 473: Ability to complete a design project under the supervision of a SEAS advisor.
- MENG 474: Ability to complete a design project under the supervision of a SEAS advisor.
- ENAS 118: Ability to design an original device or system that addresses the needs of a real client.
- ENAS 400: Ability to conceive, design, and develop a marketable product and business.
- ENAS 778: Ability to conceive, design, analyze, and demonstrate a novel robotic hardware concept.
- BENG 351: Ability to apply fundamental principles to solve problems in biology and medicine, including rational drug design.
- BENG 405: Ability to select and support a strategy to address a Grand Challenge, incorporating biotechnology and providing an expense report and timeline.

- BENG 411: Ability to design microfabrication workflows to create bioMEMS devices based on the application criteria and conduct quantitative assessment of quality control and performance measures.
- BENG 434: Ability to design a hip implant prosthesis, coronary artery, and replacement body tissues.
- CPSC 472: Ability to design a robotic system that can learn and perceive.
- EENG 406: Ability to connect material properties to aspects of solar cell design, processing, and performance.

SO 3: An ability to communicate effectively with a range of audiences.

Required Courses:

- MENG 363L: Ability to communicate experimental results in both written and oral form.
- MENG 383: Ability to produce a detailed write-up on an end-of-semester project.
- MENG 390: Ability to write a detailed term paper for an audience of peers and faculty.
- MENG 487L: Ability to create and deliver a professional-quality presentation to a panel of faculty members and external visitors.
- MENG 488L: Ability to create and deliver a professional-quality presentation to a panel of faculty members and external visitors.
- Yale College Distributional Requirements (electives in Humanities, Social Science, Writing, and Languages): Students are required to demonstrate competence at the intermediate level in a foreign language. See Chapter 5.

Electives:

- MENG 185: Ability to communicate, plan, and schedule while working on a team-based project.
- MENG 325: Ability to deliver clear presentations on additive and subtractive processes.
- MENG 400: Ability to clearly present preliminary ideas and final results for final project incorporating CAD skills used in the course.
- MENG 404: Ability to generate both written and oral deliverables to communicate progress and receive feedback from collaborators and mentors.
- MENG 459: Ability to write a clear, concise final report describing the course project.
- MENG 464: Ability to deliver a professional-quality end-of-semester presentation to one's peers and to critique presentations of fellow students.
- MENG 471: Ability to compose a written final report that clearly describes all aspects of a semester-long project and deliver two PowerPoint presentations on the project.
- MENG 472: Ability to compose a written final report that clearly describes all aspects of a semester-long project and deliver two PowerPoint presentations on the project.
- MENG 473: Ability to compose a written final report that clearly describes all aspects of a semester-long project and deliver two PowerPoint presentations on the project.

- MENG 474: Ability to compose a written final report that clearly describes all aspects of a semester-long project and deliver two PowerPoint presentations on the project.
- ENAS 118: Ability to deliver a final presentation that describes a team-based design project.
- ENAS 400: Ability to generate both written and oral deliverables to communicate progress and get feedback from interdisciplinary collaborators and mentors.
- ENAS 778: Ability to deliver a professional-quality presentation to a panel of faculty members and visitors.
- BENG 405: Ability to complete the preparation of a proposal based on the Gates Foundation Grand Challenge Exploration and present an oral summary of findings.
- BENG 411: Ability to prepare a written project report that includes background, significance, design rationale, fabrication (synthesis) procedure, in vitro and in vivo test, clinical test, and/or preparation for FDA evaluation.
- EENG 406: Ability to complete a final project and presentation that explore both the applications and limitations of photovoltaic technology.

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Required Courses:

- EENG 200: Ability to understand social impact of semiconductor devices.
- MENG 390: Ability to appreciate how computer-controlled devices can benefit society, including how they can be used to improve public health and safety.
- MENG 487L: Ability to articulate the social value of design projects, including safety analysis in the design process, and specifying the lines of accountability and competing interests.
- MENG 488L: Ability to articulate the social value of design projects, including safety analysis in the design process, and specifying the lines of accountability and competing interests.
- Yale College Distributional Requirements (electives in Humanities, Social Science, Writing, and Languages): Students learn non-technical subjects that can include courses in global affairs, cultural practices, social behavior, economics, and sustainability. (See Chapter 5.)

Electives:

- MENG 185: Ability to identify “good” and “bad” product designs.
- MENG 404: Ability to become familiar with regulatory affairs and intellectual property considerations for medical devices.
- ENAS 118: Ability to understand how engineering affects society and the environment.
- ENAS 778: Ability to understand how advanced robots can benefit public health, safety, and welfare.

- BENG 405: Ability to understand the challenges of implementing relevant biotechnologies in resource-limited environments, including technical, practical, social, and ethical aspects.
- BENG 411: Ability to understand the technology landscape in modern clinical laboratory medicine and the pressing needs that can be tackled by microfabricated tools such as microsensors, microactuators, and point-of-care devices.
- BENG 434: Ability to understand when a patent on a biomaterial should be filed.
- CPSC 472: Ability to understand the societal costs and benefits of intelligent robots.
- EENG 406: Ability to understand sustainable manufacturing processes for solar cells.
- G&G 322: Ability to understand the climate system and how human behavior affects climate change.
- G&G 342: Ability to understand climate and climate change and anthropogenic activities underlying them, planetary history, and their relation to our understanding of Earth's present dynamics and thermodynamics.

SO 5:	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

Required Courses:

- EENG 200: Ability to complete laboratory exercises in electronics as a member of a small group.
- MENG 286L: Ability to work in pairs (or, for certain labs, work with one-third of the class) to carry out labs that focus on the materials aspect of mechanical engineering.
- MENG 363L: Ability to work in small groups to execute laboratory exercises in fluid mechanics and thermodynamics.
- MENG 390: Ability to work with a partner to analyze, design, and synthesize computer-controlled engineering systems with mechanical and electrical components.
- MENG 487L: Ability to work on a team to design, construct, and test a functioning prototype engineering system.
- MENG 488L: Ability to work on a team to design, construct, and test a functioning prototype engineering system.

Electives:

- MENG 185: Ability to collaborate with others on a design project.
- MENG 325: Ability to collaborate with others on course projects that utilize several manufacturing techniques.
- MENG 404: Ability to work on a multidisciplinary team.
- ENAS 118: Ability to work as a member of a team to make a working prototype of an original device or system.
- ENAS 400: Ability to work on a team and develop effective project management and interdisciplinary communication skills.
- ENAS 778: Ability to work in small groups to conceive of, design, analyze, and demonstrate a novel robotic hardware concept.

- BENG 405: Ability to work on a team to prepare a proposal based on the Gates Foundation Grand Challenge Exploration.
- BENG 411: Ability to work on a team to complete a design project on any topic in micro- or nanobiotechnology.
- CPSC 472: Ability to work on a team to build a robotic system.

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Required Courses:

- EENG 200: Ability to build and analyze moderately sophisticated electronic circuits.
- MENG 211: Ability to formulate and analyze real-world thermodynamics problems.
- MEN 286L: Ability to characterize materials via various experimental techniques.
- MENG 363L: Ability to conduct fluid mechanics and thermodynamics experiments, analyze data, and use errors to determine how well a model describes data.
- MENG 390: Ability to design and build systems incorporating computer-controlled sensors and actuators.
- MENG 487L: Ability to perform analyses/experiments to support the capstone design project.
- MENG 488L: Ability to perform analyses/experiments to support the capstone design project.

Electives:

- MENG 185: Ability to use the method of joints and the method of sections to analyze trusses.
- MENG 325: Ability to analyze common machine elements, especially those associated with a drive train.
- MENG 365: Ability to evaluate performance data for air-breathing engines.
- MENG 404: Ability to formulate experiments to test critical hypotheses involving a project prototype for a particular medical device application.
- MENG 441: Ability to solve ordinary and partial differential equations numerically and to analyze results with a focus on accuracy and computational cost.
- MENG 459: Ability to analyze properties such as stability and energetics of multibody mechanical systems.
- MENG 469: Ability to use Mathematica and Javafoil to simulate flow over an airfoil and analyze the results.
- MENG 471: Ability to analyze and interpret data to draw conclusions.
- MENG 472: Ability to analyze and interpret data to draw conclusions.
- MENG 473: Ability to analyze and interpret data to draw conclusions.
- MENG 474: Ability to analyze and interpret data to draw conclusions.
- ENAS 118: Ability to employ data acquisition techniques and draw conclusions from this data.
- ENAS 400: Ability to analyze product concepts and business models, and draw conclusions.

- ENAS 778: Ability to analyze a novel robotic hardware concept.
- BENG 353: Ability to design and perform an experiment to measure viscoelastic response of tissues to applied stress.
- BENG 405: Ability to review and critique biotechnological solutions, including traditional and alternative technologies.
- BENG 411: Ability to conduct quantitative assessment of quality control and performance measures for bioMEMS devices.
- BENG 434: Ability to analyze behavior of a hip implant prosthesis during human activity.
- CPSC 472: Ability to analyze robotic motions.
- EENG 406: Ability to analyze photovoltaic technologies.

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Required Courses:

- EENG 200: Ability to take more advanced electronic circuits-related courses.
- MENG 211: Ability to apply thermodynamics to understand energy and environmental issues.
- MENG 363L: Ability to understand issues surrounding clean energy generation and storage.
- MENG 383: Ability to use online help documentation to learn to use unfamiliar MATLAB commands.
- MENG 390: Ability to understand component data sheets that one has not seen before and then choose correct components.
- MENG 487L: Ability to learn what needs to be learned to complete a complex project.
- MENG 488L: Ability to learn what needs to be learned to complete a complex project.

Electives:

- MENG 185: Ability to take more advanced courses in the mechanical engineering curriculum.
- MENG 325: Ability to learn new analytical tools for designing machine elements.
- MENG 365: Ability to understand the propulsion requirements for traveling to Mars.
- MENG 400: Ability to understand limitations of computational analysis software.
- MENG 404: Ability to identify pros and cons of medical device designs.
- MENG 459: Ability to mathematically abstract the dynamics of complex biomechanical systems into ordinary differential equation models.
- MENG 464: Ability to discuss and solve problems relating to interatomic/intermolecular forces and surface properties.
- MENG 469: Ability to use help documentation for Mathematica to learn about unfamiliar commands.
- MENG 471: Ability to identify appropriate set of engineering tools for an independent project.
- MENG 472: Ability to identify appropriate set of engineering tools for an independent project.

- MENG 473: Ability to identify appropriate set of engineering tools for an independent project.
- MENG 474: Ability to identify appropriate set of engineering tools for an independent project.
- ENAS 118: Ability to build off of select ideas and techniques across disciplines.
- ENAS 400: Ability to learn about current trends in entrepreneurship and business planning.
- ENAS 778: Ability to identify appropriate advanced robotic concepts that can be used to meet a specified need.
- BENG 405: Ability to learn and understand the impact of biotechnology in the developing world from an engineering perspective.
- BENG 411: Ability to understand the technology landscape in modern clinical laboratory medicine and the pressing needs that can be tackled by microfabricated tools.
- CPSC 472: Ability to develop robots with more complex functions and abilities.

Performance Criteria with Rubrics

As a means of establishing course-specific performance criteria to assess how well students are achieving Student Outcomes 1–7, rubrics that were originally designed in 2014 were updated and improved. Each course has its own set of these rubrics, tailored to the course goals, outcomes, and performance criteria, which is crucial for the process of continuous improvement described in Chapter 4. On the next several pages, Table 3-2 lists example rubrics for each of the SOs 1–7 for the required ME courses.

Each assignment in each course in the ME curriculum tests one or more Performance Criteria, each of which is mapped to a given Student Outcome (Table 3-2). The rubrics for unsatisfactory, acceptable, and exemplary are used to calibrate the grading of the course assignments and to quantify the extent to which students attain the SOs.

Table 3-2. Performance Criteria with Rubrics for each required Mechanical Engineering course.

SO 1:	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
ENAS 130: Ability to write code that solves an engineering problem using a simple numerical method.	Unable to write bug-free code and does not understand how to use numerical methods.	Can follow detailed directions to produce code to apply an appropriate numerical method to attain the desired goal.	Able to choose an appropriate numerical method and write necessary code to achieve a desired goal accurately and efficiently.
ENAS 194: Ability to apply mathematical methods to solve first- and second-order differential equations.	Does not understand differential and integral calculus.	Can solve basic differential equations.	Recognizes when to apply various solution methods to solve equations most efficiently.
EENG 200: Ability to analyze current flow through electronic circuits using differential equations.	Does not understand how to solve differential equations or how they apply to current flow.	Can solve given differential equations to determine information about current flow.	Sets up and solves differential equations to determine information about current flow.
MATH 222: Ability to determine eigenvalues and eigenvectors of a matrix.	Unable to calculate eigenvalues and eigenvectors.	Sets up calculation of eigenvalues and eigenvectors, and completes it without any math errors.	Calculates eigenvalues and eigenvectors without any math errors, and understands usefulness of these quantities.
MENG 211: Ability to analyze thermo-dynamics problems.	Lacks understanding of basic physical concepts of thermodynamics.	Can formulate thermodynamics problems in mathematical language and solve them using the principles of thermodynamics.	Can apply the concepts of thermodynamics to real engineering situations. Can analyze problems quickly and qualitatively without detailed calculations.

MENG 280: Ability to apply mathematical concepts to structural analysis.	Cannot translate engineering problems into a mathematical framework.	Can successfully apply mathematics to solve statics problems.	Develops an intuitive feel for solving statics problems efficiently. Can use mathematical skills to solve problems in unconventional ways.
MENG 285: Ability to use mathematics to characterize engineering materials.	Cannot connect principles of materials science to engineering problems.	Can formulate materials science concepts in mathematical language and subsequently solve problems.	Generalizes from methods presented in lecture to solve problems in new ways.
MENG 286L: Ability to use mathematics to analyze materials.	Cannot translate engineering problems into a mathematical framework.	Can use mathematics to quantify material properties and analyze data.	Can use mathematical methods to accomplish advanced data and error analysis.
MENG 361: Ability to use mathematics to study fluid flow.	Cannot apply vector calculus to fluids problems. Cannot translate conservation principles into mathematical form.	Can successfully translate flow problems into mathematical language and solve them.	Develops an intuitive understanding of partial differential equations describing physical systems. Can successfully generate approximate equations via non-dimensionalization.
MENG 363L: Ability to apply mathematical principles of fluid mechanics and thermodynamics to laboratory experiments.	Does not understand basic concepts of fluid mechanics and thermodynamics.	Can use mathematics to analyze laboratory data.	Can clearly link experimental data with theoretical expectations. Can perform detailed uncertainty analysis.
MENG 383: Ability to use mathematics to describe rigid-body motion in two and three dimensions.	Does not understand basic principles of conservation of energy and momentum.	Can formulate force and torque balance equations in appropriate coordinate systems.	Can solve equations of motion for general three-dimensional non-planar motion.

MENG 389: Ability to use mathematics to analyze heat transfer problems.	Cannot apply principles of control volume analysis to engineering problems.	Can set up control volumes in simple geometries, translate them into equations, and find solutions.	Can formulate and solve heat transfer problems even in complex, unsteady situations.
MENG 390: Ability to analyze control systems mathematically.	Cannot set up and solve basic ordinary differential equations.	Can successfully analyze control systems.	Can use mathematical analysis to optimize control systems.
MENG 487L: Ability to apply mathematics as needed to solve real engineering problems.	Cannot apply analysis methods learned in other classes to real problems.	Can successfully use mathematics and engineering principles to solve applied problems.	Can use mathematics and other analysis tools to optimize and compare different potential solutions to real engineering problems.
MENG 488L: Ability to apply mathematics as needed to solve real engineering problems	Cannot apply analysis methods learned in other classes to real problems.	Can successfully use mathematics and engineering principles to solve applied problems.	Can use mathematics and other analysis tools to optimize and compare different potential solutions to real engineering problems.

SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
EENG 200: Ability to design moderately sophisticated electronic circuits.	Cannot design an electronic circuit to meet given specifications.	Can design an electronic circuit that meets desired performance criteria.	Able to optimize circuit design via additional analysis and reworking.
MENG 390: Ability to analyze, design, and synthesize computer-controlled engineering systems with	Cannot design a working system to meet given specifications.	Can analyze, design, and implement a system that meets desired performance	Demonstrates ability to successively iterate in order to achieve improved functionality.

mechanical and electrical components.		criteria.	
MENG 487L: Ability to design, construct, and test a functioning prototype engineering system to meet the needs of a real-world client.	Ignores safety issues when designing. Considers an inappropriately small range of fabrication materials and methods. System does not meet all of the client's needs.	Takes safety into account when designing. Chooses appropriate materials and fabrication methods. System meets all of the client's needs.	Considers a variety of safety issues when designing. Shows breadth in fabrication choices and executes fabrication to a high level of finish. System meets all of the client's needs in an optimal way.
MENG 488L: Ability to design, construct, and test a functioning prototype engineering system to meet the needs of a real-world client.	Ignores safety issues when designing. Considers an inappropriately small range of fabrication materials and methods. System does not meet all of the client's needs.	Takes safety into account when designing. Chooses appropriate materials and fabrication methods. System meets all of the client's needs.	Considers a variety of safety issues when designing. Shows breadth in fabrication choices and executes fabrication to a high level of finish. System meets all of the client's needs in an optimal way.

SO 3: An ability to communicate effectively with a wide range of audiences.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
MENG 363L: Ability to communicate experimental results in both written and oral form.	Fails to write organized, complete reports. Unable to explain an experiment orally.	Presents results clearly and concisely in both written and oral form.	Incorporates outside information into lab reports and presentations. Clearly explains complex concepts.
MENG 383: Ability to produce a detailed write-up on an end-of-semester project.	Write-up is missing key parts of explanation.	Write-up is clear and well organized.	Write-up includes additional relevant analysis that goes beyond what was asked for.

MENG 390: Ability to write a detailed term paper that is understandable by peers and faculty.	Prepares a paper with superficial formulation, weak arguments, limited analysis, and a poor discussion.	Prepares a paper with qualitative arguments and limited analysis.	Prepares a paper with well-justified arguments for formulation, analysis, and discussion.
MENG 487L: Ability to create and deliver a professional-quality presentation to a panel of faculty members and external visitors.	Poor communicator. Unsure of message when speaking. Unprepared for presentation.	Effective communicator. Identifies topic and clearly communicates the intended message.	Clear, concise presenter. Handles questions well and displays a deep knowledge when questioned.
MENG 488L: Ability to create and deliver a professional-quality presentation to a panel of faculty members and external visitors.	Poor communicator. Unsure of message when speaking. Unprepared for presentation.	Effective communicator. Identifies topic and clearly communicates the intended message.	Clear, concise presenter. Handles questions well and displays a deep knowledge when questioned.

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
EENG 200: Ability to understand social impact of semiconductor devices.	Does not understand social impact of semiconductor devices.	Understands social impact of semiconductor devices.	Thinks creatively about ways to use semiconductor devices to improve the human condition.
MENG 390: Ability to appreciate how computer-controlled devices can benefit society, including how they can be used to improve public health and safety.	Does not understand useful aspects of computer-controlled devices.	Can repeat examples given in class on beneficial aspects of computer-controlled devices.	Generates new ways of applying computer-controlled devices to help improve public health and safety.

MENG 487L: Ability to articulate the social value of design projects, including safety analysis in the design process, and specifying the lines of accountability and competing interests.	Only demonstrates ethical behavior when prompted to do so.	Maintains high levels of integrity.	Demonstrates highest levels of ethical behavior with actions serving as role model for others.
MENG 488L: Ability to articulate the social value of design projects, including safety analysis in the design process, and specifying the lines of accountability and competing interests.	Only demonstrates ethical behavior when prompted to do so.	Maintains high levels of integrity.	Demonstrates highest levels of ethical behavior with actions serving as role model for others.

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
EENG 200: Ability to complete laboratory exercises in electronics as a member of a small group.	Does not make an effort to work with others. Leaves work undone for others to complete.	Completes own subtasks and exchanges information with others.	Helps lab partners when needed and synthesizes information from the whole group.
MENG 286L: Ability to work in pairs (or, for certain labs, work with one-third of the class) to carry out labs that focus on the materials aspect of mechanical engineering.	Does not listen to others and is incapable of teamwork. Does not participate in data collection or analysis.	Shares, listens, and engages with others on the team.	Makes the group stronger than the sum of its members.

MENG 363L: Ability to work in small groups to execute laboratory exercises in fluid mechanics and thermodynamics.	Does not participate in data collection.	Takes responsibility for part of an experiment. Efficiently shares with the rest of the group.	Demonstrates expertise and leadership without overwhelming others.
MENG 390: Ability to work with a partner to analyze, design, and synthesize computer-controlled engineering systems with mechanical and electrical components.	Works alone and does not share progress with partner, or does not do assigned tasks at all.	Completes assigned tasks and communicates information and ideas as needed with partner.	Interfaces frequently with partner to integrate system components during the design process, rather than at the end. Helps partner as needed.
MENG 487L: Ability to work on a team to design, construct, and test a functioning prototype engineering system.	Does not conscientiously work with others; fails to complete individual tasks to the detriment of the team.	Completes individual tasks well and efficiently. Interfaces with other team members.	Assists others when necessary. Helps to integrate various components.
MENG 488L: Ability to work on a team to design, construct, and test a functioning prototype engineering system.	Does not conscientiously work with others; fails to complete individual tasks to the detriment of the team.	Completes individual tasks well and efficiently. Interfaces with other team members.	Assists others when necessary. Helps to integrate various components.

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
EENG 200: Ability to build and analyze moderately sophisticated electronic circuits.	Cannot build an electronic circuit to meet given specifications and/or cannot analyze the circuit.	Can build and analyze an electronic circuit that meets desired performance criteria.	Able to build circuit. Through analysis, able to quantify the circuit's behavior and determine ways to improve it.

MENG 211: Ability to formulate and analyze real-world thermodynamics problems.	Cannot construct physical models for real-world scenarios.	Can formulate basic models that properly describe real-world situations and can solve.	Can evaluate the relative influence of all key factors and components on the behavior of a system based on a formulated model.
MENG 286L: Ability to characterize materials via various experimental techniques.	Lacks a conceptual understanding of how materials characterization and manipulation equipment works.	Understands both how equipment works and how to use it.	Can use equipment to measure material properties beyond what has been specifically asked for. Can choose appropriate equipment based on desired measurements.
MENG 363L: Ability to conduct fluid mechanics and thermodynamics experiments, analyze data, and use errors to determine how well a model describes data.	Does not understand principles, advantages, or drawbacks of measurement tools. Does not know how to use errors.	Uses proper instruments to perform accurate measurements. Analyzes data using appropriate physical principles. Can interpret errors.	Performs quantitative error analysis based on physical principles. Demonstrates understanding that data may not agree with theoretical model due to faulty measurements or to theoretical approximations.
MENG 390: Ability to design and build systems incorporating computer-controlled sensors and actuators.	Does not understand how to use sensors and actuators.	Can successfully install and calibrate appropriate sensors and actuators.	Uses empirical data to redesign systems for better performance.
MENG 487L: Ability to perform analyses/experiments to support the capstone design project.	Does not understand what needs to be tested and cannot set up appropriate experiments.	Determines and sets up relevant experiments. Analyzes data to determine whether prototype meets design constraints.	Determines experiments whose results will best point the direction toward improving the design. Analyzes results accordingly and improves design to meet any unmet constraints.

MENG 488L: Ability to perform analyses/experiments to support the capstone design project.	Does not understand what needs to be tested and cannot set up appropriate experiments.	Determines and sets up relevant experiments. Analyzes data to determine whether prototype meets design constraints.	Determines experiments whose results will best point the direction toward improving the design. Analyzes results accordingly and improves design to meet any unmet constraints.

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Performance Criterion	Unsatisfactory	Acceptable	Exemplary
EENG 200: Ability to take more advanced electronic circuits-related courses.	Inability to learn and apply course material in EENG 200.	Learns breadth of course material in EENG 200 but does not demonstrate depth of knowledge.	Demonstrates mastery of course material in EENG 200. Extends concepts to settings not covered in class.
MENG 211: Ability to apply thermodynamics to understand energy and environmental issues.	Ignores the breadth of applicability of the principles of thermodynamics.	Understands how the topics studied in thermodynamics relate to societal issues such as energy or the environment.	Actively thinks about ways to apply the principles of thermodynamics to topics of current societal impact such as energy and the environment.
MENG 363L: Ability to understand issues surrounding clean energy generation and storage.	Ignores the larger context of solar energy production and hydrogen fuel cells.	Can articulate how solar cells and hydrogen fuel cells are cleaner than large-scale technologies.	Can critically compare clean energy sources and storage technologies with technologies across several dimensions, including environmental impact and cost.
MENG 383: Ability to use online help documentation to learn to use unfamiliar MATLAB commands.	Does not know how to use the online help documentation.	Uses online help documentation. Occasionally cannot get enough information from documentation and also needs help	Understands how code examples in help documentation can be modified to suit present needs. Uses information from documentation to guide experimentation

		from other people.	with other command options.
MENG 390: Ability to understand component data sheets that one has not seen before and then choose correct components.	Does not use data sheets.	Can obtain sufficient information from data sheets in order to choose acceptable components.	Knows how to look up background information for anything on a data sheet that is unfamiliar. Chooses appropriate components from multiple options.
MENG 487L: Ability to learn what needs to be learned in order to complete a complex project.	Resorts to guessing rather than learning new material.	Learns new material using technical resources. Asks questions and brings new material to share with team members.	Teaches new material to teammates. Demonstrates an understanding that not all technical input is equally important. Attempts to identify critical technical issues.
MENG 488L: Ability to learn what needs to be learned in order to complete a complex project.	Resorts to guessing rather than learning new material.	Learns new material using technical resources. Asks questions and brings new material to share with team members.	Teaches new material to teammates. Demonstrates an understanding that not all technical input is equally important. Attempts to identify critical technical issues.

CRITERION 4. CONTINUOUS IMPROVEMENT

A. Student Outcomes

The Mechanical Engineering Program employs several assessment processes to determine the extent to which the Student Outcomes (SOs) are attained. The Program's portfolio of assessment tools includes one direct assessment method, two indirect assessment methods, and one method that incorporates both direct and indirect means of assessment:

- Course-based performance evaluation of Student Outcomes (direct assessment);
- Review of student resumes (indirect assessment);
- Exit interviews of graduating students (indirect assessment); and
- Biannual survey of alumni (direct and indirect assessment).

<u>Method 1. Course-based performance evaluation of Student Outcomes:</u>

The primary method to assess the attainment of SOs — referred to as the "Yale Method" — is embedded within each course in the Mechanical Engineering curriculum. This method, which was first used during the 2008 ABET General Review process, was well received by the ABET Program Evaluator and Team Chair (and ultimately by the Engineering Accreditation Commission), and it has been employed by the Mechanical Engineering Program ever since. Based on its success and ABET approval, the method was adopted by all of the University's ABET-accredited programs for the 2014 accreditation cycle and beyond.

The Yale Method takes advantage of the scoring mechanism used within each course and aligns individual student assignments (problem sets, exams, laboratory reports, presentations, etc.) with specific SOs. The performance of each student in a given course measures that course's contribution to achieving levels of performance for each relevant SO, as well as the amount of attention that each SO receives in that course. Because this method is implemented in each course, the data from individual courses can be aggregated to provide a comprehensive assessment of the Program's overall performance in meeting the SOs. The method requires only a small amount of additional work at the beginning of the semester to map the correlation between the coursework and the relevant outcomes. Instructions on filling out a Student Outcomes Assessment Spreadsheet for each course are provided to each faculty member at the beginning of the semester, with the completed spreadsheets then collected at the end of the term. The course-based performance evaluation is carried out by course instructors each semester, and the Program's performance as a whole is evaluated by the Mechanical Engineering Director of Undergraduate Studies (DUS) every 2–3 years. The Yale Method is described in more detail below.

The starting point for this assessment method is the Student Outcomes Assessment Spreadsheet, which contains two tabs: "Input Values" and "Outcomes Performance." An example of the "Input Values" tab is shown in Figure 4-1 for MENG 211: Thermodynamics for Mechanical Engineers. In the light blue rectangle near the top of the sheet, SOs 1–7 are listed, followed by the course number and course name. The large light green section contains the assignment grades and weightings matrix. There is a column for each assignment, as well as columns for the course letter grade and the overall course average. Each row in this section corresponds to one student, with the last row containing information about how each assignment is weighted in computing the course average. Therefore, in filling out this large section, faculty members are simply using their regular grading systems; in fact, they can easily copy and paste data from their own grading database into the Student Outcomes Assessment Spreadsheet.

Moving down the sheet, the smaller light green table is a course assessment matrix, which is a key feature of the Yale Method. An example of this matrix (again, for MENG 211) is illustrated in Figure 4-2. Reading the matrix down each column, the contribution of each assignment among the relevant SOs is provided. For example, in MENG 211, $3/5^{th}$s of each problem set assessed students on their attainment of SO 1, $1/5^{th}$ on SO 6, and the remaining $1/5^{th}$ on SO 7, whereas $4/5^{th}$s of the midterm exam covered SO 1 and $1/5^{th}$ covered SO 6. Depending on the particular course, a given assignment can cover anywhere from one SO to all 7 SOs. Reading the course assessment matrix across each row identifies key items of coursework that are relevant to each SO. The rightmost column of the course assessment matrix uses the data from the earlier columns, along with the weighting factor for each assignment (from the top portion of the spreadsheet) to compute the percentage of the course that is devoted to each of the 7 SOs.

Returning to Figure 4-1, another important feature appears below the course assessment matrix: two cells in which the instructor establishes performance cutoffs. The first cutoff marks the division between unsatisfactory and acceptable performance, while the second cutoff divides acceptable from exemplary performance. At the bottom of the “Input Values” sheet is the breakdown of student performance by assignment, which provides the number of students with unsatisfactory, acceptable, and exemplary performance on each assignment. The spreadsheet calculates these values by applying the performance cutoffs to the data obtained from the assignment grades and weightings.

To summarize, the instructor of each course inputs the following information into the “Input Values” tab:

- Individual grades for all students for each assignment;
- A “weighting factor” to each assignment;
- A fractional component of each SO that is associated with each graded assignment; and
- Cutoffs that separate the unsatisfactory, acceptable, and exemplary levels of performance for the attainment of the SOs.

The remaining tab of the Student Outcomes Assessment Spreadsheet is “Outcomes Performance,” an example of which is shown in Figure 4-3. This tab presents a course summary in the form of a bar chart. For each SO covered by the course, a colored bar indicates what percentage of the students attained exemplary performance for this SO, what percentage attained acceptable performance, and what percentage had unsatisfactory performance. The percentages are also displayed in a table to the right of the chart.

YALE SCHOOL OF ENGINEERING AND APPLIED SCIENCE

MECHANICAL ENGINEERING ABET OUTCOME REVIEW

This spreadsheet template tracks achievement of the ABET Student Outcomes.
To use this spreadsheet, fill out the parts in green - everything else should take care of itself.

ABET Student Outcomes:

1. An ability to identify, formulate, & solve complex engineering problems by applying principles of engineering, science, and mathematics
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. An ability to communicate effectively with a range of audiences
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. An ability to function effectively on a team whose members provide leadership, create collaborative and inclusive environment, establish goals, plan tasks and meet objectives
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Course Number:	MENG 211
Course Name:	Thermodynamics for Mechanical Engineers

To use this spreadsheet, fill out the parts in green - everything else should take care of itself.

The grade sheet uses faculty-assigned weighting factors for each test and homework assignment. The maximum possible points is the weighting factor * 100.

ABET Student (Yes/No)	Student Name	Pset 1 Pset 1 [100]	Pset 2 Pset 2 [100]	Pset 3 Pset 3 [100]	Pset 4 Pset 4 [100]	Pset 5 Pset 5 [100]	Pset 6 Pset 6 [100]	Pset 7 Pset 7 [100]	Pset 8 Pset 8 [100]	Pset 9 Pset 9 [100]	Pset 10 Pset 10 [100]	Pset 11 Pset 11 [100]	Pset 12 Pset 12 [100]	Extended Pset Extended Pset [200]	Midterm Midterm Exam	Assigned Grade	Overall Percent
		95	100	98	94	100	90	97	100	100	0	91	0	0	90	C	72.6%
		95	100	99	92	100	95	96	100	98	49	45	0	0	98	C	74.3%
		100	100	98	90	100	92	94	100	100	85	94	92	169	100	A	94.9%
		0	94	98	0	99	86	90	92	94	0	0	0	178	79	D	62.8%
		93	90	97	95	99	82	91	94	92	0	0	0	0	70	D	61.3%
		100	89	100	95	99	89	96	100	97	93	91	100	155	78	A	90.5%
		100	96	98	82	100	93	97	98	84	96	95	96	177	79	A	91.1%
		100	98	96	100	99	99	100	96	97	98	91	100	187	94	A	96.7%
		100	80	96	100	96	93	96	100	100	93	91	100	169	98	A	94.6%
		95	100	94	100	100	98	100	98	94	88	100	100	195	95	A	96.9%
		98	97	100	100	100	97	97	98	100	100	97	91	158	100	A	96.1%
		100	84	95	95	99	83	96	100	85	100	91	100	182	97	A	94.2%
		98	94	47	69	94	93	81	85	50	25	0	0	130	88	D	66.4%
		100	100	100	93	99	92	95	95	91	100	91	0	165	99	B	89.3%
		93	81	92	100	88	76	92	90	88	77	92	87	188	99	A	90.6%
		91	82	43	89	86	89	93	87	96	88	89	89	183	91	B	86.9%
		100	100	100	100	100	100	100	100	100	100	100	100	197	100	A	99.8%
		99	100	95	95	100	98	97	100	95	95	99	100	172	98	A	96.4%
		99	91	91	95	100	99	98	100	97	100	100	0	164	85	B	87.6%
		88	99	96	91	100	89	94	98	97	85	91	0	195	94	B	88.5%
		100	84	99	100	100	100	95	93	95	90	100	95	189	100	A	96.5%
		95	97	99	92	93	85	88	93	100	0	92	100	189	69	B	84.1%
		91	98	90	95	100	93	95	100	95	73	94	100	160	81	A	89.8%
		100	97	100	100	98	97	95	98	97	100	100	95	197	94	A	97.4%
		99	98	99	100	99	100	97	100	100	100	99	100	197	93	A	98.1%
		93	80	84	91	99	91	97	100	98	89	96	0	185	87	B	86.1%
		97	92	95	88	100	88	100	95	86	95	0	100	0	91	C	77.0%
		95	95	87	98	100	81	94	81	81	85	77	86	0	97	C	79.4%
		89	89	97	88	95	90	100	88	94	92	79	0	197	94	B	87.0%
		99	98	90	100	98	100	97	99	100	99	97	95	197	91	A	96.6%
		95	96	77	93	99	84	94	91	96	83	86	95	192	99	A	92.8%
		100	93	96	96	99	85	96	100	95	86	86	100	157	88	A	91.4%
		99	100	81	96	99	99	97	95	92	95	99	100	192	85	A	94.1%
		95	95	99	95	100	93	15	95	98	65	70	100	159	86	B	84.5%
		100	96	98	100	100	90	96	100	97	83	84	95	189	100	A	95.8%
		100	100	100	100	100	100	100	100	100	100	100	100	197	92	A	98.4%
		99	86	87	87	100	91	96	100	100	84	91	95	187	90	A	92.5%
	weighting factor	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.118	0.175		

Please assign a fraction of each of the ABET student outcomes (see 1-7 above) to each test and homework assignment. The percent of course devoted to each ABET outcome is calculated, accounting for the maximum possible points and the weighting factor.

ABET Outcome	Pset 1	Pset 2	Pset 3	Pset 4	Pset 5	Pset 6	Pset 7	Pset 8	Pset 9	Pset 10	Pset 11	Pset 12	Extended Pset	Midterm	Percent of Course
1	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.80	63.5%
2															0.0%
3															0.0%
4															0.0%
5															0.0%
6	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	20.0%
7	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		16.5%
(should sum to 1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	100.0%

This last column shows how much of outcomes 1-7 go into the course grade. This will be useful information for evaluating our program.

Please enter performance cutoff percentages below. These numbers determine the cutoff between Unsatisfactory, Acceptable, and Exemplary.

Cutoff Percentages	
72	Unsatisfactory
90	Exemplary

Breakdown of Student Performance by Assignment

*Each column should add up to the number of students in the course.

	Pset 1 [100]	Pset 2 [100]	Pset 3 [100]	Pset 4 [100]	Pset 5 [100]	Pset 6 [100]	Pset 7 [100]	Pset 8 [100]	Pset 9 [100]	Pset 10 [100]	Pset 11 [100]	Pset 12 [100]	Extended Pset [200]	Midterm Exam
Unsatisfactory	1	0	2	2	0	0	1	0	1	7	6	10	6	2
Acceptable	2	9	5	5	2	12	2	4	5	12	6	3	12	10
Exemplary	34	28	30	30	35	25	34	33	31	18	25	24	19	25

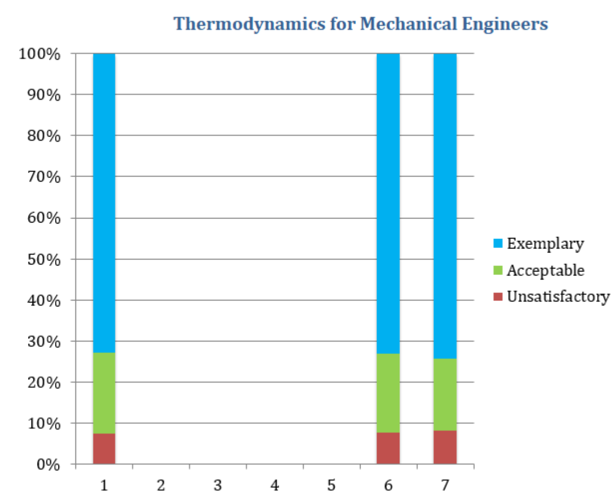
Figure 4-1. The "Input Values" tab of the Student Outcomes Assessment Spreadsheet. The example shown (with student names removed) is for MENG 211: Thermodynamics for Mechanical Engineers.

ABET Outcome	Pset 1	Pset 2	…	Pset 12	Extended Pset	Midterm	Percent of Course
1	0.60	0.60		0.60	0.60	0.80	63.5%
2							0.0%
3							0.0%
4							0.0%
5							0.0%
6	0.20	0.20		0.20	0.20	0.20	20.0%
7	0.20	0.20		0.20	0.20		16.5%
(should sum to 1)	1.00	1.00		1.00	1.00	1.00	100.0%

Figure 4-2. The Course Assessment Matrix maps coursework to relevant Student Outcomes. The example shown is for MENG 211: Thermodynamics for Mechanical Engineers.

Results: Course Summary for MENG 211

*If the chart does not appear, please select the tabular data on the right of the chart and insert your own column chart.



Outcome	Unsatisfactory	Acceptable	Exemplary	Total
1	8%	20%	73%	100%
2	0%	0%	0%	0%
3	0%	0%	0%	0%
4	0%	0%	0%	0%
5	0%	0%	0%	0%
6	8%	19%	73%	100%
7	8%	18%	74%	100%

Note that 1-7 items not evaluated (i.e., no entries in the matrix) do not have a column in the graph.

Figure 4-3. The "Outcomes Performance" tab of the Student Outcomes Assessment Spreadsheet. The example shown is for MENG 211: Thermodynamics for Mechanical Engineers.

In addition to providing a snapshot of students' attainment of SOs in a given course during a given year, the Student Outcomes Assessment Spreadsheets can also be used to track students' attainment of SOs in a given course over time. Such tracking can help to determine whether implemented changes are having the desired effect, as illustrated in the following two examples. First, as described in the 2014 Self-Study Report, two hands-on modules had been recently included in MENG 383 (Mechanical Engineering III: Dynamics) to allow students to visualize for themselves theoretical concepts discussed during lectures (such as Euler angles and conservation of angular momentum). These changes were motivated by high levels of unsatisfactory performance for SOs (a) and (e), which were at 35% and 42%, respectively, in Academic Year 2013–2014. By Academic Year 2017–2018, these unsatisfactory levels had both fallen to 10%, showing that the hands-on modules had definitely had the desired effect. Second, as described in the 2014 Self-Study Report, a change of textbook in MENG 361 (Mechanical Engineering II: Fluid Mechanics) had recently been made, with the new textbook placing more emphasis on conceptual learning. This change had been motivated by performance levels in SO (a) that were 16% unsatisfactory and only 19% exemplary. By Academic Year 2017–2018, these, the performance levels for SO (a) had changed to 12% unsatisfactory and 70% exemplary, indicating that the new textbook was significantly improving the students' ability to apply their knowledge of mathematics and engineering in MENG 361.

Another important use of the Student Outcomes Assessment Spreadsheets is to determine how well students are attaining each SO — in the Mechanical Engineering Program as a whole — by combining data from the Outcomes Performance tab of each course. This Program-wide course-based performance assessment of Student Outcomes is performed every two to three years, and the results for Academic Year 2019–2020 are discussed below.

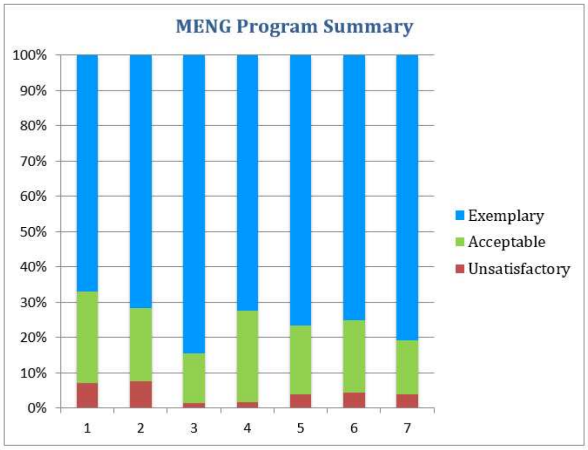
As a rough guideline, the Program seeks a rate of at least 80% attainment in the acceptable or exemplary levels of performance — that is, at most 20% unacceptable performance — for each Student Outcome covered by each course. Figure 4-4 displays the results of the Program-wide course-based performance assessment of Student Outcomes for the Academic Year 2019–2020. These results aggregate the course-based assessment data from the Student Outcomes Assessment Spreadsheets of the following 30 courses: all courses with a MENG course number (required courses as well as electives), six ENAS courses (one prerequisite [ENAS 151], two required courses [ENAS 130 and ENAS 194], and three electives [ENAS 118, ENAS 400, and ENAS 778]), and EENG 200 (required). The one required course for which assessment data were not available is MATH 222.

From Figure 4-4, it is apparent that the Program curriculum, as a whole, is significantly exceeding the 80% attainment threshold of acceptable/exemplary performance for all SOs. In fact, SO 3 ("an ability to communicate effectively with a wide range of audiences"), which students encounter mostly in laboratory and design courses, is being achieved with 85% exemplary performance, 14% acceptable performance, and only 1% unacceptable performance. At the other end of the spectrum — although really not very far from SO 3's levels at all — is another outcome that students also mostly encounter in laboratory and design courses: SO 2 ("an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors"), which shows 92% exemplary and acceptable performance combined, and 8% unacceptable performance.

To focus on the courses that are required for the B.S. degree in Mechanical Engineering, Figure 4-5 displays the same type of data as Figure 4-4, except that Figure 4-5 only includes 14 required courses. The one required course not included is MATH 222. For every SO, the average over these 14 required courses shows a lower level of exemplary performance than did the average over the 30 courses in Figure 4-4. However, each SO's level of unacceptable performance has

YALE SCHOOL OF ENGINEERING AND APPLIED

MECHANICAL ENGINEERING ABET OUTCOME REVIEW

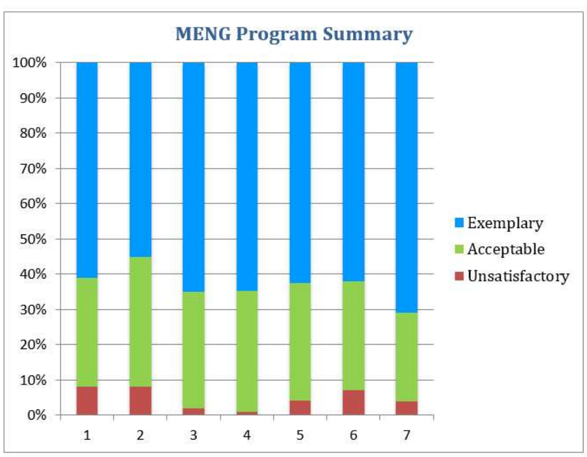


Outcomes	Unsatisfactory	Acceptable	Exemplary
1	7%	26%	67%
2	8%	21%	71%
3	1%	14%	85%
4	2%	26%	72%
5	4%	19%	76%
6	4%	20%	75%
7	4%	15%	81%

Figure 4-4. Mechanical Engineering Program-wide course-based performance assessment of Student Outcomes for the Academic Year 2019–2020. Results are aggregated over 30 courses, as listed in the accompanying text.

YALE SCHOOL OF ENGINEERING AND APPLIED

MECHANICAL ENGINEERING ABET OUTCOME REVIEW
FOR 14 REQUIRED COURSES



Outcomes	Unsatisfactory	Acceptable	Exemplary
1	8%	31%	61%
2	8%	37%	55%
3	2%	33%	65%
4	1%	34%	64%
5	4%	33%	62%
6	7%	31%	62%
7	4%	25%	71%

Figure 4-5. Mechanical Engineering Program-wide course-based performance assessment of Student Outcomes for the Academic Year 2019–2020. Results are aggregated over 14 required courses, as listed in the accompanying text.

changed very little from Figure 4-4 to Figure 4-5. The maximum is still 8% again for SO 2, and the minimum is 1%, this time for SO 4 ("an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts"). The drop in exemplary performance of each SO from Figure 4-4 to Figure 4-5 is offset by a roughly equal rise in acceptable performance. Overall, the results show that out of all of the SOs, SO 2 could use some more attention Program-wide.

Digging deeper into the results for individual required courses reveals the following information. All 14 of the courses (ENAS 130, ENAS 194, EENG 200, MENG 211, MENG 280, MENG 285, MENG 286L, MENG 361, MENG 363, MENG 363L, MENG 389, MENG 390, MENG 487L, and MENG 488L) individually achieved the Program goal, although one course did so only barely. (MENG 383's sum of acceptable and exemplary performance for SO 1 was exactly 80%.) Spreadsheets of the course-based performance assessment for all courses will be provided electronically during the ABET visit. Initiatives to improve the attainment of acceptable and exemplary levels of performance for SO 1 in MENG 383 are described in Chapter 4.B.

Lastly, it should be mentioned that the performance assessment of the SOs — in other words, the bar chart and accompanying table that appear on the "Outcomes Performance" tab of each course's Student Outcomes Assessment Spreadsheet — is available online for each of the 30 courses whose results have already been aggregated into Figure 4-4. All of these SO performance assessments appear at https://seas.yale.edu/seas-abet/2020/mechanical-engineering-student-outcomes.

Methods 2 and 3: Review of student resumes and exit interviews of graduating students:

While it is not expected that each assessment indicator provides the same result with respect to measuring the attainment of Student Outcomes, comparing data from several methods helps substantiate the findings and highlights SO outliers that warrant attention. The two solely indirect means of assessment employed by the Mechanical Engineering Program are as follows. First, the Mechanical Engineering DUS collects and reviews student resumes of each Mechanical Engineering graduate to identify engineering design experiences in the students' extracurricular, summer research, and internship activities that address the attainment of Student Outcomes. Second, the DUS also conducts exit interviews of Program graduates to gauge how they view their attainment of Student Outcomes at graduation.

Anonymized student resumes from the 17 Program graduates from the Academic Year 2019–2020 will be available electronically during the ABET visit. Exit interviews of Program graduates are conducted each year. The results from the Academic Year 2019–2020 interviews of the 17 Program graduates are presented below.

Elements that contributed to the attainment of SOs:

- Availability of undergraduate research opportunities (SO 1 and SO 6).
- Core classes that are mathematically rigorous and in-depth (SO 1).

- Small class sizes that ensure that faculty are available for students and that the Program maintains a friendly, supportive environment (all SOs).
- Well-organized project and design-based courses with opportunities for students to work in teams with engineering, as well as non-engineering students (SO2, SO5, and SO 6).
- Strong emphasis on effective communication skills (SO 3).
- Design space and community in the CEID, where each student has dedicated space and access to materials (SO 1, SO 2, SO 5, and SO 6).

Elements that did not contribute to the attainment of SOs:

- Teaching overemphasizes theoretical and mathematical concepts without placing sufficient emphasis on hands-on, real-world design experiences (e.g. manufacturing, product design, and entrepreneurship) (SO 2, SO 4, and SO 6).
- Insufficient internship opportunities, access to company recruiting, and career guidance (SO 1 and SO 2).
- Lack of incorporation of engineering skills, techniques, and software for engineering practice into courses, and few workshops and tutorials outside of class to strengthen engineering skills (SO 1, SO 2, and SO 6).
- Lack of "soft engineering design" experiences, such as green engineering, sustainability, and engineering for the developing world (SO 1, SO 2, SO 4, and SO 6).

These results emphasize that SO 2 requires additional attention in the curriculum, as was also determined via Method 1 above. However, Methods 2 and 3 show that SO 1, SO 4, and SO 6 also require attention.

Method 4: Biannual survey of alumni

Every two years, the Mechanical Engineering DUS sends a survey to all alumni of the Mechanical Engineering Program who have graduated within the past five years. The survey has three sections, the first two of which are direct assessment methods and the third of which is an indirect method. First, it asks alumni to rate, on a scale of 0 to 100 (0-did not achieve objective, 100-did achieve objective), how well the ME Program is meeting each of its Program Educational Objectives (PEOs). Second, it asks alumni to rate their ability, gained through the ME Program, in each of the SO categories, using a scale of 0 to 100 (0-no ability, 100-significant ability). Lastly, the survey asks alumni for comments about Program strengths and areas for improvement. The actual survey questions appear in Appendix H.

Thirty-six alumni responded to the 2020 Survey of Alumni of the ME Program from 2016–2020. The average responses for how well the Program is achieving its PEOs and how confident alumni feel in their ability in each of the SO categories are shown below in Table 4-1.

Table 4-1. Average responses to the 2020 Survey of Alumni of the ME Program from 2016–2020.

PEO 1	PEO 2	PEO 3	PEO 4	PEO 5	SO 1	SO 2	SO 3	SO 4	SO 5	SO 6	SO 7
81	72	65	67	56	77	70	78	68	79	74	81

Beginning with the PEOs, the Program's own expected level of attainment in meeting each of its PEOs is a rating of 70 or higher; this threshold was not made known to the survey respondents. According to survey respondents, the Program is meeting its objectives for PEO 1 and PEO 2, but not for PEOs 3, 4, and 5. (PEOs are detailed in Chapter 2.B.) To express the outcomes concisely without re-listing the PEOs here, the Program is doing well in teaching basic mathematics and science courses that underlie mechanical engineering and in training students in methods of analytical, experimental, and data analysis, but there is room for improvement in teaching design skills, communication skills, and professional/ethical responsibilities.

Regarding the SOs, the Program expects alumni to give an average confidence rating of 70 or higher; again, this information was not provided to the survey respondents. The ratings indicate that the alumni are sufficiently confident in their abilities relating to all of the SOs except for SO 4 ("An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts"). The score for SO 2 is borderline; SO 2 is "An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." Not surprisingly, SO 2 is related to PEO 3, and SO 4 is related to PEO 5. (See Table 3-1 in Chapter 3.B.)

Twenty-four of the 36 respondents responded to the final survey question, which was an open-ended comments section. Responses have been categorized below, and the responses in their entirety will be available electronically at the time of the ABET visit.

Elements that contributed to the attainment of the SOs:

- Core classes provide a solid foundation in theoretical concepts (SO 1).
- Very comprehensive senior design course (SO 2 and SO 5).
- Ample opportunity to learn and apply valuable skills outside of the classroom (SO 2, SO 3, and SO 7).
- Small size of program leads to frequent access to faculty (all SOs).
- Sense of community fostered by the Center for Engineering Innovation and Design (SO 2 and SO 5).

Elements that did not contribute to the attainment of the SOs:

- Not many opportunities to apply core class concepts to real-world problems (SO 2).
- Very few required design courses (SO 2).

- No machine design course[1] in the curriculum (SO 2).
- Little exposure to ethics, safety, the environment, and interaction with society (SO 4).
- Problem formulation and data analysis are lacking (SO 1 and SO 6).
- Not enough specialized upper-level course offerings (all SOs).
- Lack of teaching assistants in upper-level courses[2] (all SOs).
- Insufficient academic advising/guidance (all SOs).
- Too much passive learning and not enough active engagement (all SOs).
- No encouragement or preparation for taking the FE exam[3] (all SOs).
- Too many distributional requirements outside of the major[4] (all SOs).

The most common complaint — made by nearly half of the 24 respondents who wrote comments — related to the lack of design experience, especially in the first three years of the degree. As a whole, the results indicate that more attention must be paid to improving the attainment of SOs 1, 2, 4, and 6 by Mechanical Engineering students.

Documentation and records maintenance:

The DUS and lead Program Administrative Assistant are responsible for documentation and records maintenance. The DUS maintains folders for each student that expresses interest in the major during the student's first two years of study. In their junior year, most students have finalized their majors and the files for those students not in the Program are deleted. The student files contain notes concerning one-on-one meetings with the DUS, current transcripts, resumes, lists of extracurricular activities, results of Advanced Placement and other placement exams, exit interviews, and contact information. These files are kept in secure file systems for six years, then anonymized, and stored for long-term evaluation.

Lastly, it should be mentioned that for the course-based performance assessment process, the DUS collects the Student Outcomes Assessment spreadsheets for all courses taken by Program students periodically. These spreadsheets are saved in a central location and combined to produce the composite view of the Program's performance. After the spreadsheets are combined and the results are prepared, they are posted on a shared server for access by the Program faculty. This shared drive is only available by invitation, thereby protecting the sensitive information.

In addition to these records, the Department also documents the results from other assessment methods. For example, the faculty member teaching the capstone design course (MENG

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[1] This respondent must have graduated before the introduction of MENG 325 in Academic Year 2018–2019.

[2] The University allocates teaching assistant slots based on course enrollment. When the course enrollment does not meet the University-wide preset minimum of 10 (as can happen in upper-level courses in a small department), then no teaching assistant slot can be allocated.

[3] This respondent must have graduated before the Mechanical Engineering Program and the School of Engineering & Applied Science began paying for registration and study materials for any senior to take the FE exam. (See Chapter 4.B.)

[4] Distributional requirements are imposed on every undergraduate by Yale College. The Mechanical Engineering Program has no control over these requirements.

487L/488L) surveys the students to determine to what level they feel that they are meeting each of the SOs. These records are maintained as part of the course files and provided to the DUS. The Department also keeps records on the numbers of students who take (and their performance on) the Fundamentals of Engineering exam and teaching evaluations for all courses in the curriculum.

B. Continuous Improvement

The Departmental Curriculum Committee meets early during each Fall semester to discuss the Program's attainment of Student Outcomes from the data collected from the four SO assessment methods described in Chapter 4.A. The Curriculum Committee may also gather data from other sources as needed, such as websites of peer institutions (e.g., to gauge how the Yale Mechanical Engineering curriculum compares with that of other institutions) and from relevant Yale-wide reporting mechanisms. Based on all of these inputs, the Committee first develops recommendations for modifications to the Program curriculum, consults with individual faculty members, and then presents recommendations to the full Program Faculty during a meeting in mid-Fall of each year.

Below, we highlight several of the modifications to the curriculum that were recommended by the Program Faculty and then implemented to improve the Program's attainment of SOs, after the last ABET evaluation in 2014. In the places in which modifications were based on data beyond those reported in Chapter 4.A, the additional data sources are described prior to the resulting modifications.

Design-related changes to the curriculum:

During Academic Year 2017–2018, the Departmental Curriculum Committee undertook its periodic examination of Mechanical Engineering curricula at several peer institutions. The results of this examination appear in Table 4-2 on the next page. The two Yale-related columns will be explained below.

One point that is immediately obvious from the bottom row of the table is that most schools require 20 or more courses (beyond prerequisites) for completion of the major requirements, whereas Yale requires 17.5 courses for the Class of 2020 and earlier. For the Class of 2021 and beyond, this total does increase to 18.5 courses, but it is still considerably lower than several schools such as Johns Hopkins (24 courses), UIUC (also 24), Columbia (23), Stanford (22), and Princeton (also 22). The main constraint that prevents the Yale Mechanical Engineering Faculty from increasing the number of courses for completion of the major requirements is the large number of distributional requirements imposed by the University on all undergraduates. Distributional requirements are explained in greater detail in the "Broad Education Component" section of Chapter 5.A.

Table 4-2. Distribution of required courses for the B.S. degree in Mechanical Engineering at Yale and eleven peer institutions.

	Yale University: Class of 2020 & earlier	Yale University: Class of 2021 & beyond	Carnegie Mellon University	Columbia University	Cornell University	Johns Hopkins University	Massachusetts Institute of Technology	Princeton University	Rice University	Stanford University	University of California at Berkeley	University of Illinois at Urbana-Champaign	University of Michigan
Mathematics	11%	11%	5%	8%	17%	8%	5%	14%	18%	12%	6%	8%	10%
Programming	6%	5%	3%	4%	6%	4%	5%	5%	5%	4%	6%	4%	6%
Eng'g fundamentals	49%	46%	70%	49%	42%	39%	25%	45%	45%	31%	41%	48%	51%
Design	11%	22%	18%	22%	17%	28%	33%	18%	18%	29%	28%	16%	17%
Technical electives	23%	16%	5%	17%	19%	22%	32%	18%	14%	24%	19%	25%	17%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Number of courses	17.5	18.5	20	23	19.5	24	19	22	20	22	19	24	20

Explanatory notes:

- Most universities do not split courses for the Mechanical Engineering major into prerequisite courses and non-prerequisite (required and elective) courses. For purposes of the table, all courses that are prerequisites for the major at Yale — and therefore not included in this table — have been treated similarly for other universities.
- Engineering fundamentals courses are courses such as statics, thermodynamics, fluid mechanics, dynamics, heat transfer, materials science, and laboratory courses that are not directly design-related, such as fluids and materials science laboratories.
- Design courses include manufacturing courses with hands-on components, as such courses frequently include design elements.
- If a program requires that a student takes a design elective or a mathematics elective as one of the technical electives, then it has been counted in the design or mathematics category, respectively — not in the technical elective category.
- Number of courses (bottom row) refers to the number of equivalent full-credit courses. For example, if a program requires that students take two half-credit labs, then these two labs together are counted as one course.

Now focusing on the first column of data as well as the Design row in Table 4-2, it is clear that the requirements of the B.S. degree in Mechanical Engineering at Yale for the Class of 2020 and earlier have the smallest percentage of required design courses: only 11% of the required course credits. Back in Academic Year 2017–2018, when the data for the table were collected, that 11% consisted of MENG 390 (Mechatronics) and MENG 489 (Mechanical Design: Process and Implementation). At the time, MENG 489 — the senior capstone design course — was a one credit, one-semester course. Nearly every peer institution has a two-semester capstone design course, with each semester of the course counting as a full course credit. Furthermore, several other programs have at least one additional design requirement beyond a mechatronics course and a capstone design course. This additional design requirement is often either a first-year design course or an intermediate level design course. Finally, a perusal of available courses at peer institutions indicates that several schools have advanced mechanical design courses (besides the capstone design course) that students can choose as technical electives.

Based on the data from Table 4-2, the ME Program curriculum prior to 2020 was lacking in design courses relative to its peers. Furthermore, in comments during exit interviews and in further comments collected during the biannual alumni surveys (both of which are described in Chapter 4.A), several students and alumni stated that they had no background in design or manufacturing prior to entering the capstone design course during their senior year. To enhance the mechanical design curriculum and bring it into alignment with those of Yale's peer institutions, the following changes have been implemented. Note that the second column of data in the table (for Yale's Class of 2021 and beyond) will be explained in Item 3 below.

1. Expansion of senior capstone design course from one semester (MENG 489: Mechanical Design Process and Implementation) to two semesters (MENG 487L and MENG 488L: Mechanical Design: Process and Implementation I and II):

As mentioned above, Yale's capstone design course in Academic Year 2017–2018 and earlier was a one-semester course worth one Yale course credit, and it was offered under the MENG 489 course number. Beginning in Academic Year 2018–2019, MENG 489 was replaced by a two-semester course sequence consisting of MENG 487L (taken in the fall of the senior year) and MENG 488L (taken in the spring of the senior year). This significant change of moving from a one-semester course to a two-semester course sequence provides students more time to complete their projects. It also makes projects less prone to critical delays due to slow filling and shipping of orders by manufacturers. (Prior to Academic Year 2020–2021, MENG 487L and MENG 488L were each 0.5 credit. Beginning in Academic Year 2020–2021, MENG 487L will be 1.0 credit, while MENG 488L will stay at 0.5 credit.)

At the same time that the course timeline expanded, the capstone design course gained a new instructor, Dr. Booth, who has an extensive background in mechanical design. He added a significant amount of current design theory to the lectures, increased the importance of design notebooks, and began establishing projects curated from student submissions (over the summer prior to each academic year).

In prior iterations of the course, a series of deliverables was used to segment the project into manageable stages, but Dr. Booth found that this approach gave students the false impression that the deliverables were a sufficient minimum threshold of effort. Therefore, he replaced the deliverables with content-driven design reviews that focus on major design stages and the types of artifacts at each stage that are expected from engineers in industry. The assignments for these design reviews mirror the major design milestones described by Ullman (The Mechanical Design Process, 6th ed., by David G. Ullman). Each design review includes two technical staff with industry experience in mechanical and electrical engineering and Dr. Booth, and it mimics design reviews as practiced in industry, providing students with a realistic design experience and detailed feedback. Each team is given a two-week period to successfully pass a design review, providing a unique mechanism for reinforcing the importance of iteration in the design process. The results of all of these changes are a significantly improved engineering modeling phase of the design process, deeper design thinking, and a more robust design experience. Furthermore, in the 2020 Survey of Alumni, responses mentioned Dr. Booth's teaching of the capstone design course as a highlight of the Program.

There has also been a major operational improvement associated with MENG 487L/488L. Coinciding with the change in format from a one-semester design experience to a two-semester course sequence, the course location moved to its own dedicated classroom in the new Greenberg Engineering Teaching Concourse. (See Chapter 7 and Appendix C for more information about the Teaching Concourse.) For the capstone design course, the new classroom has several advantages. First, student teams each have their own area of the room and can leave their projects "in progress," as long as they shelve tools and tidy the area before leaving. In previous years, when the course was held in the CEID Studio, teams had to put away their projects completely before leaving the space, sometimes even dismantling parts of their projects because they would not otherwise fit into the assigned storage lockers. Second, the classroom in the Teaching Concourse is located just down the hall from the offices of the Technical Support Staff for the course, Mr. Weston-Murphy (mechanical support) and Mr. Ryan (electrical/electronics support). This proximity enables Mr. Weston-Murphy and Mr. Ryan to be more readily available to assist teams when needed. Third, the new space includes two new MarkForged MARK TWO GEN 2 Desktop 3D printers to support prototyping for this course. These printers are capable of continuous fiber inclusions in the extruded filament, enabling significantly improved capabilities for functional prototyping. Finally, the Teaching Concourse is located midway between the CEID, the SEAS Machine Shop, and the Student Shop, enabling students to move among these fabrication-oriented spaces easily.

<u>2. Introduction of a new intermediate-level design course (MENG 325: Machine Elements and Manufacturing Processes):</u>

Based on Table 4-2 as well as on comments in exit interviews and alumni surveys, another priority for the Program Faculty was the creation of a new sophomore/junior-level design course, MENG 325. Beginning in the Academic Year 2018–2019, Dr. Booth developed and taught MENG 325 to expose students to the fundamentals of machine design theory and manufacturing. The primary pedagogical goals are for students to understand how to design machine elements to avoid fatigue stress failures, select appropriately sized machine elements, perform basic power transmission design, select an appropriate motor for a given application, gain hands-on experience building and using a 3D printer, gain hands-on experience with lathes and mills, and be aware of a wide range of manufacturing processes available to them as engineers.

To achieve these aggressive goals, the lectures are supplemented by homework assignments that have both traditional engineering problem sets and open-ended problems where the students must define the problem constraints. The latter half of the course is defined by a student-led review of manufacturing processes and a 30- to 40-hour project that must result in a significant manufacturing experience, such as modifying a 3D printer to print an exotic material like chocolate. In Spring 2020, in response to the COVID-19 pandemic, the final manufacturing project was replaced with the analysis of a double toggle jaw crusher for crushing limestone boulders into pebbles. The project required the students to define assumptions and design constraints, perform kinematic, force, power, and fatigue analyses, build engineering models and plots in MATLAB, and document the completed design in CAD.

In MENG 325, each individual student is provided with a $200 3D printer kit which they must assemble and calibrate on their own. This mini-project, covered early in the semester, ensures that all Yale graduates have a minimum threshold of practical mechanical assembly and manufacturing experience. Many of the female engineering students have reported to Dr. Booth a significantly increased level of personal confidence in engineering as a direct result of this and the related course project.

3. Changes to the requirements for the B.S. degree in Mechanical Engineering for the Class of 2021 and beyond:

Based on the data in Table 4-2 as well as on comments in exit interviews and alumni surveys, yet another priority for the Program Faculty was to update the requirements of the Mechanical Engineering major so that students would gain more mechanical design experience. As stated previously, students in the Class of 2020 and earlier were required to take only two course credits' worth of design: MENG 390 (Mechatronics Laboratory) and MENG 487L/488L (Mechanical Design: Process and Implementation I and II). Beginning with the Class of 2021, the requirements for the B.S. degree have been updated as follows. Compared to earlier students, those graduating in 2021 and beyond are also required to take MENG 185 (Mechanical Design) and MENG 325 (Machine Elements and Manufacturing Processes). The number of technical electives required for the major has simultaneously been reduced from four to three. All other major requirements have stayed the same. Therefore, the total number of required course credits for the B.S. degree has increased from 19 courses (17.5 course credits) to 20 courses (18.5 course credits).

The second column of data in Table 4-2 shows the effect of these updated requirements. For the Class of 2021 and beyond, 22% of Yale's requirements for the B.S. degree in Mechanical Engineering are now mechanical design courses. Although four of the peer institutions still require more mechanical design courses (MIT, Stanford, UC Berkeley, and Johns Hopkins University), Yale students in the Class of 2021 and beyond will receive more design training than Mechanical Engineering students at seven other peer institutions. This represents a significant improvement from previous years, when Yale's requirements had the smallest mechanical design component of all of the peer institutions shown in Table 4-2.

4. Modifications to Mechatronics Laboratory (MENG 390):

In course evaluations several years ago, multiple students stated that the concepts taught in MENG 390 lectures seemed unrelated to the course's laboratory exercises. These complaints were the impetus for modifications that have been implemented over the past five years by Prof. Venkadesan, who took over teaching the course in the Spring 2015. The goal of the following major innovations was to improve the flow between different laboratory sessions and to better integrate the lectures with the laboratory components, so that classroom lessons are rigorously implemented in the laboratory.

First, Prof. Venkadesan created a final contest/project to frame the labs and lectures. The precise contest has varied from year to year. Topics have included the following: an autonomous three-wheeled vehicle that tracked a line on the ground while balancing a pendulum; cooperative robots that had to interact in playing a musical instrument; a light tracking device that mimicked the movements of sunflowers; a two-wheeled robot that represented the challenges of human balance control; and design and simulation of a ventilator attached to COVID-19 patients (remote project in Spring 2020). The final contest contextualizes the theoretical and hands-on exercises from the lectures and labs and provides a framework for the students to learn the material. The improved learning has been reflected in the homework assignments and the final report for the contest. The students demonstrate their theoretical depth and improved ability for systematic experimentation when debugging their robots for the final contest.

Second, Prof. Venkadesan has made changes to integrate the lectures, homework assignments, and labs more closely. The lectures go into considerable theoretical and mathematical depth about microcontrollers, actuators, electrical circuits, linear dynamic models, Laplace transforms and frequency-domain analysis, and feedback control. The homework assignments solidify the lectures through the use of real datasheets, which are used by the students in performing calculations and simulations. Concurrently, the laboratory sessions follow the homework assignments so that students gain hardware experience, in addition to theoretical knowledge. All of the labs build upon each other, to culminate in the final contest. For example, Prof. Venkadesan and the teaching support staff have designed modular hardware kits for the labs, so that each student works with the same kit throughout the semester, incrementally building the robot that they use in the final contest. In this manner, students gain intimate knowledge of all the parts of their robot and see the relationship between theory and practice.

Third, MENG 390 now includes a greater emphasis on design. Prof. Venkadesan guides the students to modify the mechanical hardware, electronics, and design control strategies for the robot used in the final contest. Thus, each robot is unique, which better prepares them for the more intensive senior capstone design class. To facilitate iterative design, almost 70% of the course deliverables are due by the mid-point of the semester. This front-loaded structure of the course content provides increased hands-on time for the students to work with their robots and develop engineering intuition.

Finally, Prof. Venkadesan has introduced an interdisciplinary approach to the course topics. For example, some of the final contest/project topics and some of the lecture content were derived from his research in biomechanics. This change in approach promotes inter-disciplinary thinking in all aspects of the course. Not only biomechanics, but other fields of research represented by other faculty at Yale are used to inspire specific questions and motivations. For example, Yale has a core strength in its School of the Environment, and one of the final contest/project topics is to design and control a light-tracking robot using a slow motor and noisy sensors, mimicking sun-tracking behavior in sunflower plants.

These improvements and their contribution to student learning led to Prof. Venkadesan receiving a university-wide competitive award, the 2018 Poorvu Prize for Excellence in Teaching. More recently, in the 2020 Survey of Alumni and in exit interviews, several students mentioned Prof. Venkadesan's teaching of the mechatronics course as a highlight of the Program. Lastly, it is added that this course, like MENG 487L/488L, is taught in the new Greenberg Engineering Teaching Concourse, thereby providing access to state-of-the-art electronics equipment and facilities, as well as proximity to lab support.

Non-design-related improvements to individual courses:

Based on input from various sources (e.g., student comments on end-of-semester course evaluations, exit interviews with the DUS, and alumni survey data), the following improvements have been implemented within individual courses.

1. Modifications to Thermodynamics for Mechanical Engineers (MENG 211):

Comments on course evaluations, during exit interviews with the DUS, and in alumni surveys indicated that certain parts of the Program curriculum lacked real-world tie-ins. Professor Cha, who taught MENG 211 for the past several years, saw an opportunity to give students a better appreciation of thermodynamics concepts. Vapor power plants that operate using an ideal or modified Rankine cycle are one of the key areas of study in thermodynamics for mechanical engineers. Throughout the semester, students practice applying the first and second law of thermodynamics to describe individual components of power plants, such as turbines, boilers, and compressors, calculate overall efficiency and power generation, and analyze how to improve efficiency in realistic power plants through the introduction of additional components like reheat cycles and cogeneration.

To help connect the concepts learned in class and calculated in problem sets to real engineering systems, Prof. Cha added a 45-minute tour of the Yale Central Power Plant to the class. The Yale Central Power Plant is representative of a vapor power plant that originally burned coal, before switching to oil and then to natural gas, providing students with an example of how mechanical engineers weigh environmental decisions (in connection to SOs 2 and 4). The Yale Central Power Plant also is a practical example of a cogeneration facility, as it supplies both electricity and steam to the Yale Campus. This tour allows students to connect concepts from class to real-world engineering problems and solutions. It also introduces students to potential career paths in mechanical engineering, by meeting actual power plant mechanics, operators, and managers.

2. Modifications to Solid Mechanics and Materials Science Laboratory (MENG 286L):

In response to comments in exit interviews and alumni surveys stating that certain parts of the

Program curriculum lacked real-world connections to engineering (as mentioned above), Prof. Schroers has significantly improved MENG 286L. The focus of the improvements has been to allow students to experience materials fabrication, testing, and usage from start to finish. A progression of labs now lead students from characterizing pure metals, to making alloys, to manipulating these alloys, to characterizing their structure and properties, and to using some of the alloys for micro- and nano-molding. The improvements were made possible through new equipment purchases funded by the Provost's Office. (See Appendix C for more details.)

For the lab in which students fabricate their own alloys from pure metals, the students make use of a new arc melter (purchased in 2015). Students told Prof. Schroers and the teaching assistants that they gained great insight from this lab, since most students had no idea how alloys are actually made. (In previous years, prefabricated alloys had been purchased.) A lab on materials manipulation uses a new vacuum furnace (purchased in 2016), which allows the students to carry out annealing treatments on their alloys and later to study the altered structural and mechanical properties of the alloys caused by the annealing treatment. Students also use two new polishers (purchased in 2019) to gain hands-on experience in basic metallurgical preparation. To characterize their alloys, students carry out stress-strain characterization and state-of-the-art nano-indentation (using the nano-indenter purchased in 2012). Nano-indentation allows them to probe the local mechanical properties of the alloy, while being exposed to modern nano-characterization methods. A new optical microscope (purchased in 2018) allows the students to visualize the microscopic changes that occur when they anneal and cold-roll their alloys, thereby increasing their understanding of property-processing relationships. These modifications to MENG 286L, enabled by the investment in new equipment funded by the Provost's Office, allowed the ME Program to improve the Materials Science part of the curriculum.

3. Modifications to Applied Numerical Methods for Differential Equations (MENG 441):

For several years in a row in the early to mid-2010s, end-of-semester course evaluations in MENG 441 (one of the possible technical electives) indicated that the course workload was too heavy. In particular, in Spring 2014 and Spring 2015, every single student completing a MENG 441 evaluation gave the course the maximum possible workload rating (equivalent to a 5 on the current scale of "1-much less" to "5-much greater"). Furthermore, this course — which is cross-listed as a graduate course — had a very small undergraduate enrollment. For example, in 2014 only three undergraduates were enrolled, and in 2015, only one undergraduate was enrolled.

To address both problems, Dr. Bennett introduced sample codes beginning in the Academic Year 2015–2016. These sample codes, which she provides in MATLAB, C++, and Fortran, act as a scaffold upon which students can build the codes that they must write to implement various numerical methods in the weekly problem sets. Each sample code typically has the input/output (I/O) portion already written, allowing students to focus their time and effort on writing the portion of each program that is more closely aligned with the primary pedagogical goal of the course: learning and implementing appropriate numerical methods.

In the three times that MENG 441 has been offered since the introduction of these sample codes, the undergraduate enrollment has increased from a previous average of two students (in 2014 and 2015) to an average exceeding 10 students, which is a significant increase. The workload rating in the course evaluations has fallen from “5-much greater” to an average of 4.3, which is between “4-greater” and “5-much greater.” Furthermore, according to student comments in the course evaluations since the sample codes have been provided, many students appreciate seeing good examples of how to format input and output. Dr. Bennett has also noticed that in the few assignments each semester in which students must write their codes completely from scratch, the I/O portions are much better written than in the years prior to inclusion of sample codes in the course.

4. Modifications to Special Projects I (MENG 471 [fall] and MENG 472 [spring]):

Student comments collected from course evaluations and data collected during alumni surveys indicated that the ME curriculum did not contain enough teaching of communication skills. As a result, starting in the Spring 2016, a course instructor was added to MENG 472, with teaching credit provided for that instruction. Prior to this semester, MENG 471 (fall course) and MENG 472 (spring course), which are independent study courses, were overseen by the DUS. The students were required to submit project prospectuses early in the semester, deliver a final presentation near the end of the semester, and submit a final written report at the end of finals period, but there were no weekly class meetings, and the DUS only handled the administrative aspects of the course. Instead, each student met regularly with his/her independent study project adviser.

As requested by the DUS and Faculty, the Spring 2016 instructor of MENG 472, Dr. Bennett, created 10 detailed slide sets and gave weekly lectures on topics such as how to: write an abstract and prospectus; develop an elevator pitch; read a technical report; avoid common writing mistakes; present data in a meaningful way; prepare an effective slide set; give a clear scientific presentation; write an executive summary; create a technical poster; and write a technical report. In addition to the existing course assignments, new ones were added: an elevator pitch, midterm presentation, executive summary, and (optional) technical poster. Furthermore, students were given extremely detailed feedback on their writing and presentation skills.

Beginning in Academic Year 2016–2017, Dr. Bennett also implemented these same changes in MENG 471, and she introduced in-class exercises in MENG 471 and 472 in which students practice a number of professional skills. For example, during one class meeting, students bring a technical paper that their adviser has asked them to read, and they apply the “three-pass” method that they learned in class. After each pass, each student briefly states to the rest of the class what he/she has learned from his/her assigned paper so far, and other students ask questions. This in-class exercise helps students make quick progress in absorbing a technical paper necessary for their independent study project, while exposing them to other sub-areas of mechanical engineering associated with other students’ projects.

Starting in the same academic year, Dr. Bennett also oversaw a pair of new courses: MENG 473 (fall) and MENG 474 (spring), both entitled Special Projects II. These courses are intended for students who have already completed either MENG 471 or MENG 472 who want to do an additional semester of independent project work. Such students do not need to repeat the professional skills component, so MENG 473 and MENG 474 do not have weekly class meetings; students also complete fewer course assignments than in MENG 471 or MENG 472.

Beginning in Academic Year 2018–2019, Dr. Booth became the instructor of MENG 471 and MENG 472. Building upon existing course materials, Dr. Booth introduced practical lectures covering software for technical writing and presentations. For example, he demonstrated the advanced functions in Word for writing research papers, writing papers in LaTeX, and using Inkscape for image generation. Dr. Booth also curated videos demonstrating good elevator pitches to help focus student achievements. In Academic Year 2019–2020, Prof. O'Hern taught MENG 472 and introduced several guest lectures focusing on intellectual property (Richard Andersson, Associate Director of Business Development, Yale's Office of Cooperative Research), start-up experiences (Ellen Su, B. S. degree in Biomedical Engineering from Yale and Chief Product Officer at Convexity Scientific, Inc.), and effective science communication to lay audiences (Robert Bazell, former Chief Science Correspondent for NBC News).

Other curriculum improvements:

Introduction of new electives into the Mechanical Engineering Program:

In response to ongoing feedback requesting more choices for Mechanical Engineering electives (for example, see the alumni survey results in Chapter 4.A, as well as the Yale-wide STEM survey results cited in the "Other Improvements to the Mechanical Engineering Program" section below), the Program has added the following electives with MENG course numbers since 2014:

- MENG 325: Machine Elements and Manufacturing Processes (which has become a required course for the Class of 2021 and beyond, as explained earlier)
- MENG 459: Neuromuscular Biomechanics
- MENG 464: Forces on the Nanoscale

Furthermore, the Program has also added many electives in other departments since 2014:

- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 350: Physiological Systems
- BENG 351: Biotransport and Kinetics
- BENG 405: Biotechnology and the Developing World
- CENG 300: Chemical Engineering Thermodynamics
- CPSC 201: Introduction to Computer Science
- CPSC 223: Data Structures and Programming Techniques
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy
- G&G 322: Physics of Weather and Climate
- G&G 342: Introduction to Earth and Environmental Physics
- PHYS 301: Introduction to Mathematical Methods of Physics
- S&DS 220: Introductory Statistics, Intensive
- S&DS 230: Data Exploration and Analysis

Students may now choose from a total of approximately 30 technical electives. The Departmental Curriculum Committee and the DUS review the list of electives each year and update it as needed. In response to student suggestions, a new elective is added if the Committee and the DUS deem that it is appropriate after reading the course syllabus and possibly discussing the course emphasis with its instructors.

Other improvements to the Mechanical Engineering Program:

In late February 2019, Program Faculty received the results of a Yale-wide survey of students entitled, “Annual Report of the Yale College Student Advisory Committee on Science and Quantitative Reasoning,” which was dated Feb. 18, 2019. This report summarized survey results for several topics, such as general experiences within a student’s specific major (i.e., interactions with the department that is home to his/her major), experiences in introductory lecture and laboratory courses, and knowledge of resources provided by the Office of Science and Quantitative Reasoning. Over 800 responses from STEM majors were received, 52 of which were from majors in Mechanical Engineering and Engineering Sciences-Mechanical. (For survey purposes, no distinction was made between the two majors.) Results from the report appear in Table 4-3.

Table 4-3. MENG-related results from Annual Report of the Yale College Student Advisory Committee on Science and Quantitative Reasoning.

Topic	MENG responses	Context for MENG responses
Classes larger than expected?	54% yes	STEM average: 46% yes
Answers below are on a scale of 1 to 5 (1-poor, 2-fair, 3-good, 4-very good, 5-excellent).		
Supportiveness of department	3.0	MENG ranked 13th out of 18 STEM departments in survey; no average rating provided.
Responsiveness of department	3.4	MENG ranked 13th out of 18; average rating was 3.7.
Departmental events	3.4	MENG ranked 13th out of 18; no average rating provided.
Departmental support in undergraduate research	3.2	MENG ranked 15th out of 18; no average rating provided.
Diversity of faculty members in department	3.4	MENG ranked 10th out of 18; no average rating provided.
Departmental selection of electives	2.7	MENG ranked 15th out of 18; average rating was 3.4.

It is apparent that there is considerable room for the Department of Mechanical Engineering & Materials Science (MEMS) — and, by extension, the Mechanical Engineering Program — to increase its support of students. Note that the departmental selection of electives has continued to increase in recent years, as described in the "Other Curriculum Improvements" section above. Below are two additional ways in which the Program has begun to address this perceived lack of support.

1. Registration and payment of ASME student memberships:

The MEMS Department, in collaboration with the School of Engineering & Applied Science, has offered to register students for memberships in the American Society of Mechanical Engineers (ASME) and to pay their membership fees as long as they are enrolled at the university. As stated on the ASME website (www.asme.org/membership/why-become-a-member/student-member-benefits), membership in ASME "offers networking events, student competitions, volunteer opportunities, and access to key resources" that help students to prepare for professional careers. Since the MEMS Department instituted this policy of registering and paying for ASME student memberships in Academic Year 2019–2020, more than 20 students have taken advantage of it.

2. Financial support for students taking the Fundamentals of Engineering (FE) exam:

In the 2020 Survey of Alumni, one respondent stated that when he/she was a student, there was no publicity or encouragement regarding taking the FE exam. In fact, the MEMS Department, in collaboration with the School of Engineering & Applied Science, has offered to pay for registration and study materials for Mechanical Engineering seniors to take the FE Mechanical Engineering exam. Passing this exam confers upon students the Engineer-In-Training (EIT) designation. While preparing for the exam, students must review materials covered throughout the Mechanical Engineering curriculum, including mathematics, ethics, physics, engineering fundamentals (statics, dynamics, materials, fluid mechanics, thermodynamics, and heat transfer), and mechanical design. Therefore, by supporting students who are taking the exam, the Program is indirectly helping students to increase their proficiency in many of the Program's Student Outcomes. Since the MEMS Department instituted this policy in Academic Year 2018–2019 of financially supporting students taking the FE exam, more than 10 Mechanical Engineering seniors have taken advantage of it.

A major facilities-related improvement that has impacted the Mechanical Engineering Program:

The investments made to the physical infrastructure supporting the Mechanical Engineering program since 2014 have been significant. As detailed in Chapter 7, as well as in press reports during this period (e.g., see https://yaledailynews.com/blog/2017/11/16/new-lab-space-centralizes-seas/) the creation of the Linda and Glenn H. Greenberg Engineering Teaching Concourse was one such improvement that also contributed to the Program's success. This facility was opened in 2017 to provide new lab space and equipment for all of Yale's engineering programs, thereby replacing the previous labs that were constructed over 50 years ago. Of note is the donation of all new electronics equipment within the facility by a Yale Engineering alum, thus signaling one example of the strong affiliation of our alumni and the Program.

The Teaching Concourse includes six independent dry labs and two wet labs. Three labs are fully outfitted for program delivery related to electronic/electromechanical systems, and a fourth lab is configured as open work space to support mechanical design courses. As multidisciplinary spaces that were designed to offer full visibility into each lab from a common hallway, the new labs have the added benefit of being a showcase for the Program's laboratory courses. By design, prospective students, visitors, and other members of the Yale community have an unimpeded view of the actions and activities of the Program's students and faculty as they learn and work in a state-of-the-art facility. The new facilities are highly valued by the program's students and faculty as they provide spacious room, modern design, and advanced equipment to engage in design projects. This infrastructure investment has also been accompanied by an investment in rapid prototyping equipment. This equipment, along with resources provided in the SEAS Machine Shop, the Center for Engineering Innovation and Design (CEID), the Mechanical Design Laboratory, and the Student Shop, provides Mechanical Engineering students with ready access to a variety of manufacturing resources.

This investment by Yale University in undergraduate engineering programs has been a valuable improvement to the student experience. In addition to that impact, two other examples highlight contributions of the new labs. As a physical space with dedicated resources, including three staff members who support lab courses, the Teaching Concourse became a central node in the Program's response to education challenges associated with the pandemic. The lab and staff immediately mobilized to create new methodologies to deliver lab content remotely by capitalizing on remote delivery of existing systems and the creation of remote lab kits. The education support team within the Teaching Concourse outfitted spaces with new technology to conduct remote instruction and coordinated activities to share education innovations related to online instruction. As a central facility with a dedicated staff, the coordinated efforts directly benefitted the program.

As a second example of the expanded value of the labs, Yale's President Peter Salovey promotes the new teaching labs as one of three components in Yale's Innovation Corridor. President Salovey's vision is that these three new 10,000 square foot facilities (Greenberg Engineering Teaching Concourse, Center for Engineering Innovation and Design, and the Tsai Center for Innovative Thinking at Yale) catalyze Yale's ability to bring together students from across campus to share their diverse perspectives and inspire their ingenuity. The program has and is expected to continue to benefit from the Administration's support for its commitment to student learning.

Improvements to the Mechanical Engineering Program planned for Academic Year 2020–2021 and beyond:

The Program Faculty are planning a number of improvements to the Mechanical Engineering Program in the near future. All of the improvements involve changes to the curriculum, and they also require approval from the university-wide Yale Course of Study Committee.

1. Increase in course credit for MENG 487L (Mechanical Design: Process and Implementation I) from 0.5 credit to 1.0 credit:

One observation from the Departmental Curriculum Committee's comparison of the Yale Mechanical Engineering curriculum with Mechanical Engineering curricula at peer institutions (see Table 4-2 and surrounding text) was that most other institutions have two-semester senior capstone design sequences, with each semester's course carrying one full course credit. In addition, student feedback via end-of-semester course evaluations has repeatedly indicated that Yale's capstone design course — both in its former one-semester version (1.0 credit for MENG 489) and its current two-semester version (0.5 credit for MENG 487L and 0.5 credit for MENG 488L) — has a total workload that far exceeds other one-credit courses in the major. Furthermore, the Program Faculty would like course instructor Dr. Booth to cover additional topics (such as advanced machine design and manufacturing) in the two-semester sequence, but he is currently constrained by the fact that each semester carries only 0.5 credit.

As a result, Mechanical Engineering DUS Prof. O'Hern and Dr. Booth petitioned the Yale Course of Study Committee for permission to increase the amount of course credit for MENG 487L (taken in the fall of the senior year) from 0.5 credit to 1.0 credit. The petition involved detailed information about course assignments, estimated workload, and a justification as to why all of the stated material must be included in the course (as opposed to simply reducing the number of assignments and leaving the course at 0.5 credit). In mid-July 2020, Prof. O'Hern and Dr. Booth learned that the petition had been approved. Therefore, beginning in the Fall 2020, MENG 487L will carry one full course credit. Program Faculty are currently considering whether to submit a similar petition to increase MENG 488L from 0.5 credit to 1.0 credit.

2. Introduction of a new advanced design elective, MENG 425 (Advanced Design and Analysis of Machines):

As mentioned earlier in the text discussing Table 4-1, a comparison of the Yale Mechanical Engineering curriculum with curricula at peer institutions indicated that several programs have advanced mechanical design courses (besides the capstone design course) that students can choose as technical electives. Furthermore, feedback through assessment tools, such as exit interviews and alumni surveys (see Chapter 4.A), has repeatedly shown that the Mechanical Engineering curriculum can improve by adding more design courses. As a result, the Program Faculty, at the suggestion of the Departmental Curriculum Committee, is pursuing the development of an advanced design elective. This proposed new course is MENG 425, Advanced Design and Analysis of Machines.

Mechanical Engineering DUS Prof. O'Hern petitioned the Yale Course of Study Committee in Spring 2020 for permission to offer MENG 425 beginning in the Spring 2021. This course is the result of significant student demand to supplement the topics in MENG 325, Machine Elements and Manufacturing Processes, which covers machine design and manufacturing, including predicting fatigue failure of various machine parts and a very brief introduction on applying this knowledge to select, pre-defined mechanisms that are commonly found in machines. In fact, a poll of the 24 students — mostly junior Mechanical Engineering majors — taking MENG 325 in the Spring 2020 indicated that most of them are interested in taking MENG 425 in the Spring 2021.

MENG 425 seeks to provide topics that cannot be covered in MENG 325 due to time constraints. The syllabus and course materials for MENG 425 have been developed by Dr. Booth (who teaches MENG 325) and Dr. Adrezin (an adjunct teaching faculty member who has taught courses in the Program before, including MENG 400, Computer Aided Design, in the Spring 2020). Topics in MENG 425 include advanced mechanism analysis, mechanism synthesis, designing welding assemblies for strength and fatigue, and providing a practical project that allows students to fully realize a complex machine design. MENG 425 fills an important gap in the curriculum — primarily one of kinematics and advanced machine design. Both of these topics are standard components of the Mechanical Engineering programs at many peer institutions. In the petition submitted to the Yale Course of Study Committee, it was proposed that Dr. Adrezin teach the new course in the Spring 2021. The Yale Course of Study Committee gave provisional approval for the Program to offer MENG 425 initially as an elective in the Spring 2021 and then make it a required course for the Class of 2025 and beyond.

3. Increase in course credit for MENG 286L (Solid Mechanics and Materials Science Laboratory) from 0.5 credit to 1.0 credit and addition of WR status:

One of the observations from the comparison of the Yale Mechanical Engineering curriculum with the curricula of eleven peer institutions (see earlier in Chapter 4.B) was that one-third to one-half of Yale's peer institutions require two full course credits of materials science. Yale's current B.S. degree requirements for Mechanical Engineering include 1.5 course credits of materials science: 1.0 credit via MENG 285 (Introduction to Materials Science) and 0.5 credit via MENG 286L (Solid Mechanics and Materials Science Laboratory).

For this reason, as well as the fact that multiple equipment purchases made over the past few years (see Appendix C) now put Prof. Schroers in the position of being able to develop additional laboratory exercises that were not previously possible, the Departmental Curriculum Committee has decided to pursue two improvements to MENG 286L. First, with the addition of new laboratory exercises to help students make stronger connections between theoretical concepts and hands-on experience, the workload of MENG 286L is expected to increase. Second, the Curriculum Committee sees MENG 286L as an ideal context in which to expand the teaching of technical writing skills — a topic that is already covered to some extent in the current version of the course. (Students currently must submit an outline for a major team-based lab writeup and then meet with Prof. Schroers for feedback and corrections before finishing the write-up.)

While technical writing skills are very important from the perspective of being able to communicate effectively as an engineer, the acquisition of writing skills in general is also important in terms of fulfilling the academic requirements imposed by Yale College on all its undergraduates. The means by which the University keeps track of the acquisition of writing skills is through a WR designation (WR=writing course). This designation is granted to certain courses by the Yale College Writing Center Advisory Committee, but only after the Committee conducts a review of the course content to ensure that writing skills are covered in sufficient depth. By the end of sophomore year, all students must take at least one WR course credit, and by the end of junior year, all students must take at least two WR course credits (including the one taken by the end of sophomore year). Currently there is only one course in the Mechanical Engineering curriculum that carries the WR designation: MENG 363L (Fluid Mechanics and Thermodynamics Laboratory), which is a one-credit course. Many Mechanical Engineering students use MENG 363L as the second of their two WR course credits, thus reducing the number of courses outside their major that they must take to fulfill University-wide distributional requirements.

Given the proposed changes to MENG 286L, Prof. Schroers will submit a petition to the Yale Course of Study Committee in Fall 2020 to increase MENG 286L from 0.5 course credit to 1.0 course credit. The petition will also include a request for the Yale College Writing Center Advisory Committee to grant the course a WR designation to recognize the significant writing skills component in the proposed expansion of MENG 286L. Approval of this designation would lessen the burden of the Yale College distributional requirements on students in the ME Program. In particular, because many students take MENG 286L during their sophomore year, they would be able to count the course as the first of their two WR course credits. Contingent upon the Committees' approval, the Program Faculty plan to offer MENG 286L as a one-credit WR course starting in the Academic Year 2021–2022.

4. Proposed modifications to Mechanical Engineering III: Dynamics (MENG 383):

As discussed in Chapter 4.A, MENG 383's sum of acceptable and exemplary performance for SO 1 during Academic Year 2019–2020 was 80%, meaning that 20% of the students exhibited unsatisfactory performance in SO 1. It should also be recalled that 20% unsatisfactory performance is the maximum level that the Program is willing to tolerate for any SO in any individual course. Therefore, to improve the attainment of acceptable and exemplary levels of performance for SO 1, the instructor of the course, Prof. O'Hern, will implement the following changes to MENG 383 during the Academic Year 2020–2021. Prof. O'Hern will include new course content devoted to (1) nonlinear dynamics and chaos, (2) pattern formation, and (3) vibrational response in random spring networks. The inclusion of these advanced topics is intended to introduce students to the forefront of research in the field of dynamics, while also increasing student engagement. Additionally, these topics bridge ideas from previous courses; for example, vibrational response in spring networks teaches students how the structural properties of static systems — covered in MENG 280 (Mechanical Engineering I: Strength and Deformation of Mechanical Elements) — influence dynamical response. The new topics will be paired with a guest lecture from Prof. Mark Shattuck of the Department of Physics, City College of New York, who will give a seminar-style presentation entitled "Pattern formation in vibrated granular media," which will provide an experimental context for many of the topics covered during the lectures.

C. Additional Information

Copies of all of the assessment instruments and materials discussed in Chapter 4.A and Chapter 4.B will be made available electronically for review during the ABET visit.

CRITERION 5. CURRICULUM

A. Program Curriculum

Table 5-1 appears on the next two pages and describes the curricular path to attain the B.S. degree in Mechanical Engineering for the Class of 2020. (Note that the requirements for the B.S. degree in Mechanical Engineering for the Class of 2021 and beyond have changed and will be described in detail in Chapter 4. For the Class of 2021, two courses with significant design content were added as requirements, MENG 185 and MENG 325, and one of the four electives was removed. All other requirements remain the same.) As can be seen from the table, Yale is on a semester system. There are 10.0 course credits (33.0 semester credit hours) in Math and Basic Sciences (i.e., mathematics, physics, and chemistry) and 14.5 course credits (50.5 semester credit hours) in Engineering Topics courses. The total of 24.5 course credits for the B.S. degree in Mechanical Engineering is broken down into 17.5 course credits for required courses and 7.0 course credits for prerequisites. Four of the Engineering Topics courses are electives that can be chosen from a pool of more than 30 courses that are taught at least every other year. Most Mechanical Engineering students choose Mechanical Design (MENG 185) as one of their four electives, so we have included this course in Table 5-1, in addition to three other electives.

In addition to the 24.5 credits required for the B.S. degree in Mechanical Engineering, there are 12.0 credits necessary to satisfy the distributional requirements for Yale College. Thus, to obtain the B.S. degree in Mechanical Engineering, students need 36.5 credits, while the Yale College minimum for graduation is 36.0 course credits.

It should be noted that the table shows the Mechanical Engineering curriculum for a student who, upon entering Yale, has minimal preparation in mathematics and chemistry. As described in Chapter 1.F, a student who passes an advanced prerequisite in mathematics is automatically considered to have demonstrated proficiency in the lower-level mathematics prerequisite courses without actually taking them; in chemistry, a student may fulfill the chemistry prerequisite via a sufficiently high score on the Advanced Placement (AP) exam. Example course sequences for students with advanced preparation in mathematics are provided at https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/undergraduate-curriculum-2020.

Table 5-1 is discussed in greater detail later in this chapter, in the subsection entitled "How the Curriculum Meets Requirements for Math & Basic Sciences and Engineering Topics."

Table 5-1. Curriculum.

B.S. in Mechanical Engineering

Course (Department, Number, Title) List all courses in the program by term starting with the first term of the first year and ending with the last term of the final year.	Indicate whether course is Required, Elective or a Selected Elective by an R, an E or an SE.[1]	Subject Area (Credit Hours)			Last Two Terms the Course was Offered: Year and, Semester, or Quarter	Maximum Section Enrollment for the Last Two Terms the Course was Offered[2]
		Math & Basic Sciences	Engineering Topics; Check if Contains Significant Design (✓)	Other		
First-Year Fall:						
MATH 112: Calculus of Functions of One Variable I		3.0			F19, SP20	139
PHYS 180: University Physics I		4.0			F18, F19	277
PHYS 165L: General Physics Laboratory I		1.5			F18, F19	277
MENG 185: Mechanical Design	E		4.0✓		F19, SP20	29
One Humanities/Social Science/Writing/Language Elective				3.0	F19, SP20	
First-Year Spring:						
MATH 115: Calculus of Functions of One Variable II		3.0			F19, SP20	267
PHYS 181: University Physics II		4.0			SP19, SP20	230
PHYS 166L: General Physics Laboratory II		1.5			SP19, SP20	250
ENAS 130: Introduction to Computing for Engineers and Scientists	R	3.0			F19, SP20	66
One Humanities/Social Science/Writing/Language Elective				3.0	F19, SP20	
Sophomore Fall:						
ENAS 151: Multivariable Calculus for Engineers		3.0			F19, SP20	84
MATH 222: Linear Algebra with Applications	R	3.0			F19, SP20	131
MENG 280: Mechanical Engineering I: Strength and Deformation of Mechanical Elements	R		4.0		F18, F19	46
MENG 285: Introduction to Materials Science	R		3.0		F18, F19	42
One Humanities/Social Science/Writing/Language Elective				3.0	F19, SP20	

Sophomore Spring:						
ENAS 194: Ordinary and Partial Differential Equations with Applications	R	3.0			F19, SP20	76
MENG 211: Thermodynamics for Mechanical Engineers	R		3.0		SP19, SP20	37
MENG 286L: Solid Mechanics and Materials Science Laboratory	R		1.5✓		F19, SP20	25
Two Humanities/Social Science/Writing/Language Electives				6.0	F19, SP20	
Junior Fall:						
EENG 200: Introduction to Electronics	R		3.0✓		F18, F19	61
CHEM 163: Comprehensive University Chemistry I		4.0			F18, F19	97
MENG 361: Mechanical Engineering II: Fluid Mechanics	R		4.0		F18, F19	52
MENG 383: Mechanical Engineering III: Dynamics	R		4.0		SP19, F19	41
One Humanities/Social Science/Writing/Language Elective				3.0	F19, SP20	
Junior Spring:						
MENG 363L: Fluid Mechanics and Thermodynamics Laboratory	R		3.0✓		SP19, SP20	20
MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science	R		4.0		SP19, SP20	19
MENG 390: Mechatronics Laboratory	R		4.0✓		SP19, SP20	31
One Humanities/Social Science/Writing/Language Elective				3.0	F19, SP20	
Senior Fall:						
MENG 487L: Mechanical Design: Process and Implementation I	R		2.0✓		F18, F19	22
Two MENG Electives	E		6.0✓		F19, SP20	
Two Humanities/Social Science/Writing/Language Electives				6.0	F19, SP20	
Senior Spring:						
MENG 488L: Mechanical Design: Process and Implementation II	R		2.0✓		SP19, SP20	22
One MENG Elective	E		3.0		F19, SP20	
Three Humanities/Social Science/Writing/Language Electives				9.0	F19, SP20	
TOTALS (in terms of semester credit hours)		33 Hours	50.5 Hours	36 Hours		
Totals must satisfy minimum credit hours.	Minimum Semester Credit Hours	30 Hours	45 Hours			

1. **Required** courses are required of all students in the program, **Elective** courses (often referred to as open or free electives) are optional for students, and **Selected Elective** courses are those for which students must take one or more courses from a specified group.
2. For courses that include multiple elements (lecture, laboratory, recitation, etc.), indicate the maximum enrollment in each element. For Selected Elective courses, indicate the maximum enrollment for each option.

Instructional materials and student work verifying compliance with ABET criteria for the categories indicated above will be required during the campus visit.

Alignment of the curriculum with the Program Educational Objectives:

In this section, we describe the alignment of the courses in the curriculum (Table 5-1) to our five Program Educational Objectives (PEOs in Chapter 2.B). We note that several changes have recently been made in the requirements for the B.S. degree in Mechanical Engineering to increase the alignment of the curriculum with the PEOs. Chapter 4 describes how the senior capstone design course changed from being a one-semester, one-credit course (MENG 489 — last offered in the Academic Year 2017–2018) to a fall-spring course sequence (MENG 487L and MENG 488L), with each of the two courses carrying one-half credit. Chapter 4 also describes the fact that for the Class of 2021 and beyond, two courses with significant mechanical design content, MENG 185 and MENG 325, were added as requirements for the B.S. degree in Mechanical Engineering and the number of electives was reduced from four to three.

In the remainder of this section, we examine the alignment of the curriculum (using the major requirements that applied to the Class of 2020 and earlier) with the PEOs. As mentioned near the start of Chapter 5.A, many students in the Class of 2020 (and earlier) have taken Mechanical Design (MENG 185) as one of their four electives, so we specifically included this course in Table 5-1. However, in the lists below, we take into account the fact that MENG 185 is, in fact, not a required course for the Class of 2020.

To determine which courses contribute to each of the PEOs, we begin by making use of the mapping between ABET Student Outcome (SO) and PEOs, which appeared in Chapter 3.B. It should also be noted that the SOs addressed by each course are provided in each course syllabus in Appendix A, along with specific outcomes of instruction. This information, coupled with the mapping, allows us to create the following lists of courses that contribute to satisfying each of the Program Educational Objectives. These lists show that many courses are aligned with each PEO.

PEO 1: To provide a comprehensive introduction to the basic science and mathematics courses that provides the foundation of mechanical engineering.

Prerequisites:

- CHEM 163: Comprehensive University Chemistry I
- MATH 112: Calculus of Functions of One Variable I
- MATH 115: Calculus of Functions of One Variable II
- ENAS 151: Multivariable Calculus for Engineers
- PHYS 180: University Physics I
- PHYS 181: University Physics II
- PHYS 165L: General Physics Laboratory I
- PHYS 166L: General Physics Laboratory II

Required Courses:

- ENAS 130: Introduction to Computing for Engineers and Scientists
- ENAS 194: Ordinary and Partial Differential Equations with Applications
- EENG 200: Introduction to Electronics

- MATH 222: Linear Algebra with Applications
- MENG 211: Thermodynamics for Mechanical Engineers
- MENG 280: Mechanical Engineering I: Strength and Deformation of Mechanical Elements
- MENG 285: Introduction to Materials Science
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 361: Mechanical Engineering II: Fluid Mechanics
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II

Electives:

- MENG 185: Mechanical Design
- MENG 325: Machine Elements and Manufacturing Processes
- MENG 365: Chemical Propulsion Systems
- MENG 400: Computer-Aided Engineering
- MENG 404: Medical Device Design and Innovation
- MENG 441: Applied Numerical Methods for Differential Equations
- MENG 459: Neuromuscular Biomechanics
- MENG 464: Forces on the Nanoscale
- MENG 469: Aerodynamics
- MENG 471: Special Projects I (fall)
- MENG 472: Special Projects I (spring)
- MENG 473: Special Projects II (fall)
- MENG 474: Special Projects II (spring)
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 350: Physiological Systems
- BENG 351: Biotransport and Kinetics
- BENG 353: Introduction to Biomechanics
- BENG 405: Biotechnology and the Developing World
- BENG 411: BioMEMS and Biomedical Microdevices
- BENG 434: Biomaterials
- CENG 300: Chemical Engineering Thermodynamics
- CPSC 201: Introduction to Computer Science
- CPSC 223: Data Structures and Programming Techniques
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy
- G&G 322: Physics of Weather and Climate
- G&G 342: Introduction to Earth and Environmental Physics
- PHYS 301: Introduction to Mathematical Methods of Physics

- S&DS 220: Introductory Statistics, Intensive
- S&DS 230: Data Exploration and Analysis

PEO 2: To provide thorough training in methods of analytical, experimental and data analysis, including problem formulation.

Required Courses:

- EENG 200: Introduction to Electronics
- MENG 211: Thermodynamics for Mechanical Engineers
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II

Electives:

- MENG 185: Mechanical Design
- MENG 325: Machine Elements and Manufacturing Processes
- MENG 365: Chemical Propulsion Systems
- MENG 400: Computer-Aided Engineering
- MENG 404: Medical Device Design and Innovation
- MENG 441: Applied Numerical Methods for Differential Equations
- MENG 459: Neuromuscular Biomechanics
- MENG 464: Forces on the Nanoscale
- MENG 469: Aerodynamics
- MENG 471: Special Projects I (fall)
- MENG 472: Special Projects I (spring)
- MENG 473: Special Projects II (fall)
- MENG 474: Special Projects II (spring)
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 353: Introduction to Biomechanics
- BENG 405: Biotechnology and the Developing World
- BENG 411: BioMEMS and Biomedical Microdevices
- BENG 434: Biomaterials
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy

PEO 3: To provide the fundamentals of the design process including project innovation, synthesis and management both individually and in a team setting.

Required Courses:

- EENG 200: Introduction to Electronics
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II

Electives:

- MENG 185: Mechanical Design
- MENG 325: Machine Elements and Manufacturing Processes
- MENG 400: Computer-Aided Engineering
- MENG 404: Medical Device Design and Innovation
- MENG 469: Aerodynamics
- MENG 471: Special Projects I (fall)
- MENG 472: Special Projects I (spring)
- MENG 473: Special Projects II (fall)
- MENG 474: Special Projects II (spring)
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 351: Biotransport and Kinetics
- BENG 405: Biotechnology and the Developing World
- BENG 411: BioMEMS and Biomedical Microdevices
- BENG 434: Biomaterials
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy

PEO 4: To provide both technical and nontechnical programs that develop strong oral and written communication skills.

Required Courses:

- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II
- Yale College Distributional Requirements (electives in Humanities, Social Science, Writing, and Languages)

Electives:

- MENG 185: Mechanical Design

- MENG 325: Machine Elements and Manufacturing Processes
- MENG 400: Computer-Aided Engineering
- MENG 404: Medical Device Design and Innovation
- MENG 459: Neuromuscular Biomechanics
- MENG 464: Forces on the Nanoscale
- MENG 471: Special Projects I (fall)
- MENG 472: Special Projects I (spring)
- MENG 473: Special Projects II (fall)
- MENG 474: Special Projects II (spring)
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 405: Biotechnology and the Developing World
- BENG 411: BioMEMS and Biomedical Microdevices
- EENG 406: Photovoltaic Energy

PEO 5: To instill in our students an understanding of their professional and ethical responsibilities that impact society and their profession.

Required Courses:

- EENG 200: Introduction to Electronics
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II

Electives:

- MENG 185: Mechanical Design
- MENG 404: Medical Device Design and Innovation
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 778: Advanced Robotic Systems
- BENG 405: Biotechnology and the Developing World
- BENG 411: BioMEMS and Biomedical Microdevices
- BENG 434: Biomaterials
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy
- G&G 322: Physics of Weather and Climate
- G&G 342: Introduction to Earth and Environmental Physics

Curriculum's support of the attainment of Student Outcomes

Regarding the curriculum's support of the attainment of Student Outcomes, the course-based performance evaluation process described in Chapter 4 illustrates how the Mechanical Engineering curriculum promotes SO attainment. In essence, this component of our assessment process is an explicit pairing between the relevant problems/assignments in each course and specific SOs.

It is important to recall that recent curriculum changes have been made for those in the Class of 2021 and beyond receiving the B.S. degree in Mechanical Engineering to bolster their attainment of all SOs. For example, two design-focused courses (MENG 185 and MENG 325) are now required for the major; these changes are described in greater detail in Chapter 4. Mechanical Design (MENG 185) covers all 7 SOs, while Machine Elements and Manufacturing Process (MENG 325) covers all SOs except SO 4.

For the curriculum taken by the Class of 2020 and earlier, the coverage of Student Outcomes within each course is detailed in Table 5-2. This table shows which courses have demonstrable performance criteria for each of the SOs 1 through 7. We see that the mapping of each SO to a number of different courses ensures that students receive sufficient breadth and depth in each SO. The SOs satisfied in each course are also indicated on each course syllabus in Appendix A.

Table 5-2. Relationship between curriculum and attainment of Student Outcomes.

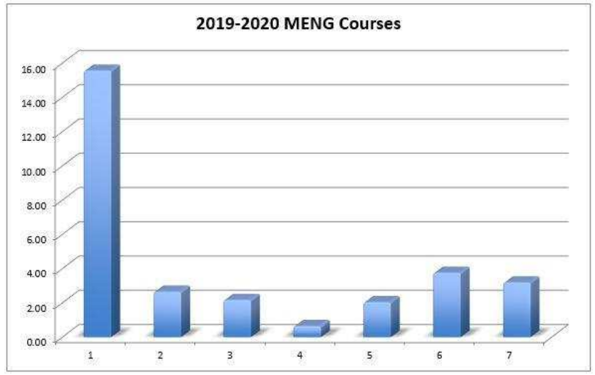
Curriculum↓	Student Outcomes→	1	2	3	4	5	6	7
Prerequisites								
CHEM 163	Comprehensive University Chemistry I	x						
MATH 112	Calculus of Functions of One Variable I	x						
MATH 115	Calculus of Functions of One Variable II	x						
ENAS 151	Multivariable Calculus for Engineers	x						
PHYS 180	University Physics I	x						
PHYS 181	University Physics II	x						
PHYS 165L	General Physics Laboratory I	x						
PHYS 166L	General Physics Laboratory II	x						
Required Courses								
ENAS 130	Introduction to Computing for Engineers and Scientists	x						
ENAS 194	Ordinary and Partial Differential Equations with Applications	x						
EENG 200	Introduction to Electronics	x	x		x	x	x	x
MATH 222	Linear Algebra with Applications	x						
MENG 211	Thermodynamics for Mechanical Engineers	x					x	x
MENG 280	Mechanical Engineering I: Strength and Deformation of Mechanical Elements	x						
MENG 285	Introduction to Materials Science	x						
MENG 286L	Solid Mechanics and Materials Science Laboratory	x				x	x	
MENG 361	Mechanical Engineering II: Fluid Mechanics	x						
MENG 363L	Fluid Mechanics and Thermodynamics Laboratory	x		x		x	x	x

MENG 383	Mechanical Engineering III: Dynamics	x		x				x
MENG 389	Mechanical Engineering IV: Fluid and Thermal Energy Science	x						
MENG 390	Mechatronics Laboratory	x	x	x	x	x	x	x
MENG 487L	Mechanical Design: Process and Implementation I	x	x	x	x	x	x	x
MENG 488L	Mechanical Design: Process and Implementation II	x	x	x	x	x	x	x
Electives (at least 4)								
MENG 185	Mechanical Design	x	x	x	x	x	x	x
MENG 325	Machine Elements and Manufacturing Processes	x	x	x		x	x	x
MENG 365	Chemical Propulsion Systems	x					x	x
MENG 400	Computer-Aided Engineering	x	x	x				x
MENG 404	Medical Device Design and Innovation	x	x	x	x	x	x	x
MENG 441	Applied Numerical Methods for Differential Equations	x					x	
MENG 459	Neuromuscular Biomechanics	x		x			x	x
MENG 464	Forces on the Nanoscale	x		x				x
MENG 469	Aerodynamics	x	x				x	x
MENG 471	Special Projects I (fall)	x	x	x			x	x
MENG 472	Special Projects I (spring)	x	x	x			x	x
MENG 473	Special Projects II (fall)	x	x	x			x	x
MENG 474	Special Projects II (spring)	x	x	x			x	x
ENAS 118	Introduction to Engineering, Innovation, and Design	x	x	x	x	x	x	x
ENAS 400	Making It: Product Design and Entrepreneurship	x	x	x		x	x	x
ENAS 778	Advanced Robotic Mechanisms	x	x	x	x	x	x	x
BENG 350	Physiological Systems	x						
BENG 351	Biotransport and Kinetics	x	x					
BENG 353	Introduction to Biomechanics	x					x	
BENG 405	Biotechnology and the Developing World	x	x	x	x	x	x	x
BENG 411	BioMEMS and Biomedical Microdevices	x	x	x	x	x	x	x
BENG 434	Biomaterials	x	x		x		x	
CENG 300	Chemical Engineering Thermodynamics	x						
CPSC 201	Introduction to Computer Science	x						
CPSC 223	Data Structures and Programming Techniques	x						
CPSC 472	Intelligent Robotics	x	x		x	x	x	x
EENG 406	Photovoltaic Energy	x	x	x	x		x	
G&G 322	Physics of Weather and Climate	x			x			
G&G 342	Introduction to Earth and Environmental Physics	x			x			
PHYS 301	Introduction to Mathematical Methods of Physics	x						
S&DS 220	Introductory Statistics, Intensive	x						
S&DS 230	Data Exploration and Analysis	x						

On the next page, Figure 5-1 summarizes Table 5-2 by showing the fractions of each Student Outcome that appear in each required course (and several of the elective courses for a total of

YALE SCHOOL OF ENGINEERING AND APPLIED SCIENCE

MECHANICAL ENGINEERING ABET OUTCOME REVIEW



	Other							MENG Courses							
Out-comes	EENG 200	ENAS 118	ENAS 130	ENAS 151	ENAS 194	ENAS 400	ENAS 778	185	211	280	285	286L	325	361	363L
1	31.3%	17.7%	100.0%	100.0%	100.0%	16.5%	5.0%	22.1%	63.5%	100.0%	100.0%	33.5%	49.0%	100.0%	20.4%
2	32.5%	12.8%	0.0%	0.0%	0.0%	4.5%	15.0%	13.2%	0.0%	0.0%	0.0%	0.0%	30.5%	0.0%	0.0%
3	0.0%	15.0%	0.0%	0.0%	0.0%	23.0%	10.0%	14.8%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	15.3%
4	1.3%	10.0%	0.0%	0.0%	0.0%	0.0%	20.0%	7.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	12.0%	12.0%	0.0%	0.0%	0.0%	20.5%	15.0%	19.9%	0.0%	0.0%	0.0%	33.5%	0.2%	0.0%	5.5%
6	12.0%	12.0%	0.0%	0.0%	0.0%	17.8%	12.5%	7.8%	20.0%	0.0%	0.0%	33.0%	4.0%	0.0%	39.1%
7	11.0%	20.5%	0.0%	0.0%	0.0%	17.8%	22.5%	14.6%	16.5%	0.0%	0.0%	0.0%	14.3%	0.0%	19.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	MENG Courses																
Out-comes	365	383	389	390	400	404	441	459	464	469	471	472	474	487L	488L	Total Course Credits
1	57.3%	95.5%	100.0%	38.2%	48.4%	4.8%	89.1%	55.7%	52.0%	78.1%	18.0%	18.0%	20.0%	13.5%	8.1%	15.56
2	0.0%	0.0%	0.0%	7.9%	25.8%	18.9%	0.0%	0.0%	0.0%	4.9%	17.0%	17.0%	18.0%	22.7%	24.0%	2.65
3	0.0%	1.1%	0.0%	2.6%	6.5%	6.6%	0.0%	10.0%	20.0%	0.0%	27.0%	27.0%	24.0%	5.3%	6.5%	2.17
4	0.0%	0.0%	0.0%	7.9%	0.0%	4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.0%	5.8%	0.64
5	0.0%	0.0%	0.0%	10.8%	0.0%	40.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.1%	18.0%	2.04
6	40.2%	0.0%	0.0%	19.2%	0.0%	20.5%	10.9%	24.3%	0.0%	8.0%	18.0%	18.0%	18.0%	20.7%	19.7%	3.76
7	2.4%	3.4%	0.0%	13.4%	19.4%	3.8%	0.0%	10.0%	28.0%	8.9%	20.0%	20.0%	20.0%	14.8%	17.8%	3.19
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	30.00

Figure 5-1. Contribution of each course to Student Outcomes 1–7.

30 Program courses) in the ME curriculum during the Academic Year 2019–2020 as determined from activities within the courses. The mathematics courses (ENAS 151, ENAS 194, and MATH 222 [not shown]), computational courses (ENAS 130 and MENG 441), and selected Mechanical Engineering courses (MENG 280, MENG 285, MENG 361, and MENG 389) evaluate only Student Outcome 1, while the other courses evaluate two, three, four, or more Student Outcomes. Student Outcome 1 received the most course coverage, and five other outcomes were above one course credit: SO 2, SO 3, SO 5, SO 6, and SO 7. Note that SO 4 had the smallest number of course credits, but it is covered in several electives, BENG 405, BENG 411, BENG 434, EENG 406, G&G 322, and G&G 342, for which we did not collect student work. Note that all of the Student Outcomes are evaluated in the Mechanical Engineering curriculum.

Prerequisite structure of the Program's required courses:

This section describes the prerequisite structure of the Mechanical Engineering Program. Additional details are provided in Chapter 1 and online at https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/undergraduate-curriculum-2020. For the Class of 2021 and beyond, additional details are available at http://catalog.yale.edu/ycps/subjects-of-instruction/mechanical-engineering/. It is noted that the terminology courses and credits are more or less interchangeable at Yale, with the majority of courses awarded one credit; the exceptions relevant for Mechanical Engineering students are that certain laboratory courses are awarded only one-half credit.

The Program requires prerequisite courses in mathematics and physics, as well as a chemistry lecture course requirement. In mathematics, the students must take, as prerequisites, courses up to and including Multivariable Calculus (ENAS 151 or MATH 120). In physics, students must take two terms of Calculus-based Physics (PHYS 180 and 181, or PHYS 200 and 201, or PHYS 260 and 261) and both of the associated laboratory courses (PHYS 165L and 166L, or PHYS 205L and 206L). Note that each of these physics laboratory courses are one-half credit each. The flowchart (Figure 5-2) below provides a guide for the mathematics and physics prerequisites for ME majors.

The specific set of prerequisites taken during the first year depends on the student's high school background and perceived capabilities. First-year students are advised by the ME DUS to seek the proper course level: a student should not repeat material taken in high school, nor should a student overreach and then perform poorly in a class. At Yale, students do not register for a course until 10 days after the term begins ("the Yale shopping period"). The shopping period allows students to sample the intensity and pace of multiple courses and to select courses appropriately. To assist the student in finding the appropriate introductory course, the different Physics courses are not held at the same time, and mathematics courses are taught in multiple sections with varying meeting times to avoid scheduling conflicts.

In certain subject areas, Yale College students can earn "acceleration credits" for prior academic work, as evidenced either by sufficiently high scores on Advanced Placement (AP) exams or by completing advanced courses taken during first year without having taken prerequisites. With a large enough number of acceleration credits, students can complete their undergraduate degree in fewer than eight semesters. (Acceleration credits do not count toward the number of credits needed for graduation, nor toward distributional requirements, if the student graduates "on time" in eight semesters.) In the Mechanical Engineering Program, it is possible for students to receive acceleration credit for courses in mathematics only. In terms of fulfilling the mathematics prerequisites for the Mechanical Engineering major, a student who passes an advanced prerequisite is automatically considered to have demonstrated proficiency in the lower-level prerequisite courses. See Chapter 1.F for a more detailed description of acceleration credits and ways of demonstrating proficiency in prerequisites.

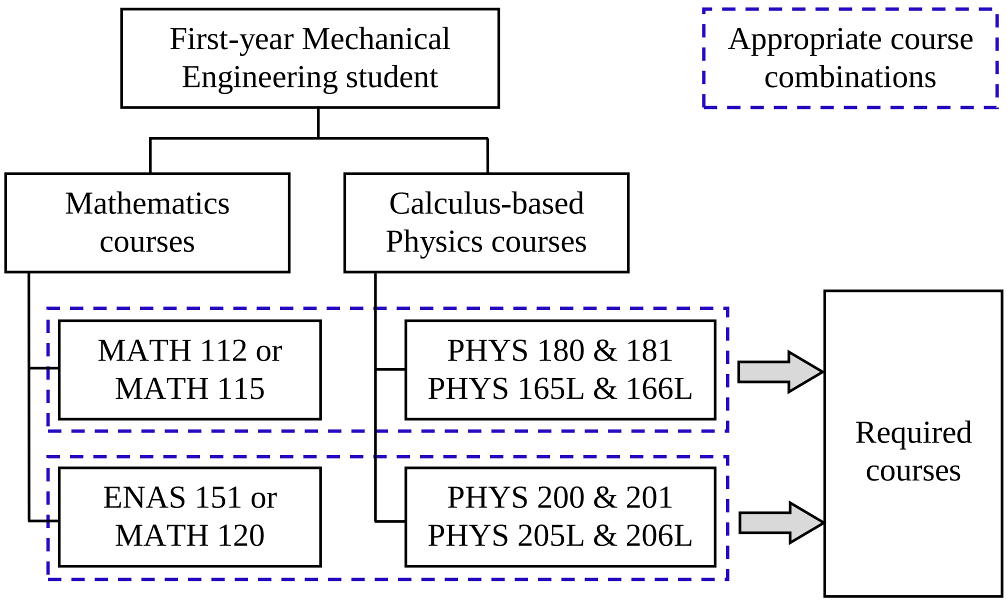


Figure 5-2. Flowchart illustrating the prerequisite structure for mathematics and physics in the Mechanical Engineering Program.

The goal of the chemistry requirement for the Mechanical Engineering Program is to bring students to proficiency in one semester of chemistry (CHEM 161 or higher). Yale does not award acceleration credit for high scores on the AP Chemistry exam. However, Mechanical Engineering students with sufficient chemistry experience can satisfy the chemistry requirement via a 4 or 5 on the AP Chemistry exam (or a 7 on the IB Chemistry exam or an A in A-Level Chemistry course). In this case, fulfillment of the chemistry requirement is tracked by the DUS via official copies of the relevant exam scores of the student. Alternatively, students may satisfy the chemistry requirement by completing an appropriate introductory chemistry course at another university, subject to approval from the DUS of Chemistry.

<u>How the Curriculum Meets Requirements for Math & Basic Sciences and Engineering Topics:</u>

A Yale Baccalaureate degree requires at least 36.0 credits, typically completed in 8 semesters (4 years). Yale University operates on a semester system. Each semester consists of 13 weeks of classes followed by a short reading period. Final examinations take place immediately following the end of reading period. The majority of Yale Engineering classes offer 2.5 hours of lectures per week (three 50-minute classes or two 75-minute classes) with an additional problem or recitation section. Laboratory and design-oriented classes typically offer one to two hours of lecture per week with additional hours spent in the lab. Since the laboratory and design classes are run in an open format, students typically spend considerably more time than the formally scheduled times.

Table 5-1 shows the Mechanical Engineering curriculum for the minimum preparation in mathematics and chemistry, which totals 36.5 Yale course credits (119.5 credit hours). The courses are divided into three categories: Math and Basic Sciences; Engineering Topics; and Other. These categories contain 10.0 course credits (33.0 credit hours), 14.5 course credits (50.5 credit hours), and 12.0 course credits (36.0 credit hours), respectively.

The 10.0 Math and Basic Sciences course credits are as follows:

- Comprehensive University Chemistry I (CHEM 163, or another introductory chemistry course)
- Calculus of Functions of One Variable I (MATH 112)
- Calculus of Functions of One Variable II (MATH 115)
- Multivariable Calculus for Engineers (ENAS 151)
- University Physics I (PHYS 180)
- University Physics II (PHYS 181)
- General Physics Laboratory I (PHYS 165L)
- General Physics Laboratory II (PHYS 166L)
- Introduction to Computing for Engineers and Scientists (ENAS 130)
- Ordinary and Partial Differential Equations with Applications (ENAS 194)
- Linear Algebra with Applications (MATH 222).

The 14.5 Engineering Topics course credits are as follows:

- Introduction to Electronics (EENG 200)
- Mechanical Design (MENG 185 – which nearly all Mechanical Engineering students take as one of their four electives)
- Thermodynamics for Mechanical Engineers (MENG 211)
- Mechanical Engineering I: Strength and Deformation of Mechanical Elements (MENG 280)
- Introduction to Materials Science (MENG 285)
- Solid Mechanics and Materials Science Laboratory (MENG 286L – 0.5 course credit)
- Mechanical Engineering II: Fluid Mechanics (MENG 361)
- Fluid Mechanics and Thermodynamics Laboratory (MENG 363L)
- Mechanical Engineering III: Dynamics (MENG 383)
- Mechanical Engineering IV: Fluid and Thermal Energy Science (MENG 389)
- Mechatronics Laboratory (MENG 390)
- Mechanical Design: Process and Implementation I (MENG 487L – 0.5 course credit)
- Mechanical Design: Process and Implementation II (MENG 488L – 0.5 course credit)
- and three additional electives.

The remaining 12.0 course credits are in the Other category. These courses are electives in humanities, social sciences, writing, and languages.

Regarding the sequence of courses, preparation for a strong foundation in mathematics, physics, chemistry, and computation is typically started in the first year and completed in the sophomore year. Introduction to design often begins in the first year with the introductory course Mechanical Design (MENG 185). Starting in the second year, students begin their Engineering Topics sequence with courses in Strength and Deformation of Mechanical Elements (MENG 280), Materials Science (MENG 285), and Thermodynamics (MENG 211). This sequence continues in the junior year with courses in Fluid Mechanics (MENG 361), Fluid and Thermal Energy Science (MENG 389), Dynamics (MENG 383), Electronics (EENG 200), and Mechatronics (MENG 390). Laboratory courses in Mechanical Engineering begin in the sophomore year and continue through the senior year. During senior year, students fulfill their senior requirement via a yearlong process and implementation design course (MENG 487L and MENG 488L). It is noted that MENG 487L and MENG 488L together comprise a team-based capstone design experience. The three additional Mechanical Engineering electives (not including MENG 185, which many students take as their first elective) can be taken whenever the appropriate prerequisites have been completed.

Broad education component:

As stated on the Yale Admissions Office website, "Yale is committed to the idea of a liberal arts education through which students think and learn across disciplines, liberating or freeing the mind to its fullest potential. The essence of such an education is not what you study, but the result: gaining the ability to think critically and independently and to write, reason, and communicate clearly – the foundation for all professions… There are no specific classes you must take at Yale, but you are required to learn broadly and deeply." Students broaden their education by choosing from among hundreds of humanities, social science, and natural science courses, while they also learn one subject area (their chosen major) in depth.

To ensure that students have a broad educational experience, Yale College imposes specific graduation requirements relating to disciplinary areas and to skills. Regarding disciplinary areas, students are required to take no fewer than two course credits in the humanities and arts (Hu), two course credits in the sciences (Sc), and two course credits in the social sciences (So). The two course credits in the sciences are fulfilled by the ME Program requirements in Chemistry and Physics. Students must also fulfill skills requirements by taking two course credits in quantitative reasoning (QR), two course credits in writing (WR), and courses to further their foreign language proficiency. The two required course credits in quantitative reasoning are fulfilled by the prerequisite and/or required mathematics courses for the ME Program. Depending on their level of accomplishment in foreign languages at matriculation, students may fulfill this last requirement with one, two, or three courses or by a combination of coursework and approved study abroad.

Courses that fulfill the distributional requirements are designated in the course listings in Chapter IV of the Yale College Programs of Study (YCPS) by the abbreviations Hu, Sc, So, QR, WR, and, for the foreign language requirement, L1, L2, L3, L4, or L5. (See http://catalog.yale.edu/ycps/yale-college/distributional-requirements/.) Credits earned in courses completed on a Credit/D/Fail basis may not be used to fulfill any of the distributional requirements, nor may credits earned in independent study, tutorial, directed research, or directed reading courses. In addition, acceleration credits may not be applied toward fulfillment of distributional requirements. Thus, the minimum distributional requirement for a student with minimal language proficiency is 9 course credits (2 in the humanities and arts, 2 in the social sciences, 2 in writing, and up to 3 language course credits). To recognize the significant writing skills component of the Fluid Mechanics and Thermodynamics Laboratory course (MENG 361L), this course carries the WR designation granted by the Yale College Writing Center Advisory Committee, which lessens the burden of the distributional requirements on students in the ME program.

Given that Mechanical Engineering students must take courses (as described above) to fulfill distributional requirements, and that many of these courses come from nontechnical subject areas, the broad education component of the Yale undergraduate experience complements the technical content of the Mechanical Engineering curriculum. Furthermore, the nontechnical courses that students take in Humanities, Social Sciences, Writing, and Languages help them to practice and strengthen their oral and written communication skills. Therefore, the broad education component is consistent with Program Educational Objective 4: To provide both technical and nontechnical programs that develop strong oral and written communication skills.

The explanation of how the ME Program curriculum addresses the ME Program Criteria is detailed in the "Program Criteria" Chapter of this report, immediately before the Appendices.

Major Design Experience that Prepares Students for Engineering Practice:

Engineering Design is an integral part of the Mechanical Engineering Program. Students have significant opportunities to pursue engineering design through the curriculum (the engineering design course sequence and several laboratory courses), the Center for Engineering Innovation and Design (CEID), and extracurricular activities that are sponsored by the School of Engineering & Applied Science. These components of the curriculum are detailed in the following paragraphs.

- ME Engineering Design Curriculum

  Mechanical Design (MENG 185): Students typically take this elective course in their first or second year. The course introduces the student to the design process and the mechanical engineering major through drafting/CAD, fabrication methodologies, and basic engineering science content (mechanics of materials, strength and deformation, and machine elements) to correlate engineering design with engineering science. Emphasis is placed on management of the design process (planning, scheduling, and decision-making), on application of fundamental physics to hardware development, and on written communication (including drafting and sketching). The laboratory portion of the class includes a team-based design project. In recognition of the importance of Mechanical Engineering Design in the curriculum, MENG 185 is now a required course for the B.S. degree in Mechanical Engineering for the Class of 2021 and beyond. (See Chapter 4.)

Machine Elements and Manufacturing Processes (MENG 325): Introduced in 2018, this elective course provides a working knowledge of two fundamental topics related to mechanical design: machine elements and manufacturing processes. Students are introduced to the most common machine elements (linkages, gears, bearings, springs, and common actuators) and learn analytical tools to design systems with them. Students also study the basics of common commercial manufacturing processes for mechanical systems, including low-volume processes such as machining to high-volume processes such as casting (metal parts), molding (plastic parts), and stamping (sheet metal parts). The course includes short design assignments, three small projects, and a final project that gives students significant experience with manufacturing and analysis. The course content builds off of MENG 185 and students are expected to have extensive CAD experience (e.g., from MENG 185) before taking this course. In recognition of the importance of Mechanical Engineering Design in the curriculum, MENG 325 is now a required course for the B.S. degree in Mechanical Engineering for the Class of 2021 and beyond. (See Chapter 4.)

Medical Device Design and Innovation (MENG 404): This elective course is a hands-on design-based course where interdisciplinary teams of students employ fundamentals of design thinking and the engineering design process to ideate novel solutions to clinical challenges posed by Yale School of Medicine clinicians and medical device company engineers. Students conceptualize, fabricate, and test device prototypes, in addition to receiving guest lectures in medicine, medical technology, regulatory affairs, entrepreneurship and intellectual property and field trips to medical device companies such as Medtronic. Co-taught by instructors from the School of Engineering & Applied Science and the Yale School of Medicine, the course leverages resources at the CEID. Each time this course has been offered, it has received 3–4 times as many applicants as there are available slots. Work done in MENG 404 has led to several student first-author publications, one patent disclosure, and several media articles. Numerous projects have continued beyond the course, and one was approved for a human clinical trial. Two recent news articles about the course appeared as https://seas.yale.edu/news-events/news/students-present-medical-innovations and https://yaledailynews.com/blog/2019/02/22/engineering-students-design-medical-device-prototypes/.

Making It: Product Design and Entrepreneurship (ENAS 400): Positioned at the intersection of design, technology, and entrepreneurship, this elective course introduces students to the many facets of product design and development, while simultaneously working to conceive of a novel product and business strategy. The first four weeks of the course are used to gain a deeper understanding of the early stages of the product development process. During this time, students are guided through the design and fabrication of a Bluetooth® speaker. Topics include sketching, CAD, physical and digital prototyping, and basic electronics, in addition to various other industrial design tools, strategies, and techniques. At the end of this period, each student will have fabricated their own Bluetooth® speaker. Lectures for the remainder of the course consist of a collection of topics relevant to the development of innovative products: design strategies, customer discovery, intellectual property, part sourcing, manufacturing, product validation, sustainability, business model generation, lean startup, and funding mechanisms. In addition, several guest entrepreneurs provide insights into their entrepreneurial trajectories. During this phase of the course, students working in teams of ~4 also conceptualize, design, and develop prototypes for a novel product or service. Each project team is considered its own “startup” and is required to develop a business model, funding strategy, and deployment plan. The end of the semester culminates in a juried presentation of the course projects and the embedded technology within each product, as well as a business plan for each product.

<u>Special Projects I (MENG 471 [fall], MENG 472 [spring]):</u> Mechanical Engineering students who take this elective — usually during either the fall or spring of their senior year so that they can build off of knowledge gained in previous courses — complete a faculty-supervised one- or two-person lab- or design-based project. Prior to the start of the semester, students schedule appointments with the ME DUS to discuss potential projects and advisors. Once a project and advisor have been identified, students begin the process of researching, designing, and implementing their ideas. Students write a prospectus (due near the end of the second week of the semester), a midterm report, and a final report. They also give two PowerPoint presentations (at the middle and end of the semester) to fellow classmates and the faculty. Throughout the semester, the entire class meets weekly to work on developing professional skills such as writing abstracts, technical reports, and executive summaries as well as learning good practices for preparing posters, presenting data effectively, and delivering presentations. Students also meet regularly with their advisors.

<u>Special Projects II (MENG 473 [fall], MENG 474 [spring]):</u> Students who have completed either MENG 471 or MENG 472 (Special Projects I, described in the preceding paragraph) and who wish either to extend their previous design project or work on a new one can do so under the MENG 473 or MENG 474 course number. This course is similar in format to Special Projects I, except that the students are not required to deliver an elevator pitch or give a mid-semester presentation, and there are no weekly class meetings. Only one course, MENG 471 or 472, can count as an elective toward the B.S. degree in Mechanical Engineering. MENG 473 and 474 cannot be counted toward the B.S. degree in Mechanical Engineering, but they can be used as course credits toward the Yale College requirement of a total of 36.0 course credits.

<u>Mechanical Design: Process and Implementation I and II (MENG 487L and MENG 488L):</u> These two halves of a yearlong capstone design sequence are taken during the fall and spring semesters of the senior year. In this course sequence, student teams implement real-world design projects, each of which has a customer that provides feedback, a hardware objective, and an open-ended problem definition that allows room for creative solutions. Students experience the entire design process including concept generation, project management, teamwork, prototype development, and detailed design. Teams perform analyses and experiments to support the design effort, incorporate appropriate engineering standards, fabricate and test their engineered systems, document the entire design process, and present their results to a technical audience.

- Laboratory Classes Associated with Design in the ME Curriculum

In addition to the two required basic physics laboratory classes, students take four engineering laboratory courses (for a total of 3.5 credits) that include engineering design components. More detail about these laboratory courses appears below.

Introduction to Electronics (EENG 200): This course provides an introduction to the basic principles of analog and digital electronics, which involves the analysis, design, and synthesis of electronic circuits and systems. Topics include current and voltage laws that govern electronic circuit behavior, node and loop methods for solving circuit problems, DC and AC circuit elements, AC power, frequency response, nonlinear circuits, semiconductor devices, and small-signal amplifiers. Laboratory sessions involve the design, measurement, and analysis of circuits covering the course material.

Solid Mechanics and Materials Science Laboratory (MENG 286L): This course is generally taken during the second semester of sophomore year after students take Introduction to Materials Science (MENG 285) in the first semester of that year. This laboratory course introduces students to a variety of materials processing, mechanical testing, and microstructure characterization techniques of engineering materials. It offers hands-on opportunities through both fixed and open-ended laboratory projects for students to apply knowledge of solid mechanics and materials science to evaluate the linkage between the mechanical behavior of materials and their underlying microstructures and their roles in manufacturing and engineering design.

Fluid Mechanics and Thermodynamics Laboratory (MENG 363L): This course, generally taken during the second semester of the junior year after the lecture course in Fluid Mechanics (MENG 361), introduces students to experimental methods of analysis for both incompressible and compressible fluid flow. Emphasis is placed on the quantitative correspondence between the theory of fluid flow and laboratory realizations. This laboratory course is a full-credit course that focuses on the fundamentals of fluid mechanics as well as experiments, design, and applications of thermal and fluid sciences. The Writing Center Advisory Committee (of Yale College) has recognized the course's strong emphasis on exemplary writing practices and significant writing component by designating it as fulfilling the writing skill (WR) distribution requirement.

Mechatronics (MENG 390): This course is designed to teach fundamentals and provide experience in designing and implementing electronic control of mechanical systems. The lectures cover topics on mathematical modeling, analysis, and design of dynamic systems that include electronic, electrical, and mechanical components. Topics covered include mathematical models of mechanical and electrical systems, system dynamics, sensors, actuators, microcontrollers, and feedback control. Lab exercises throughout the semester provide hands-on experience in implementing many of these topics. The labs and homework assignments lead up to the goal of a final team-based project where the teams build, program, and control autonomous two-wheeled balancing robots that compete against each other in a variety of tasks, including speed racing and line following around a convoluted path.

- Center for Engineering Innovation and Design (CEID) and the ME Curriculum

There are a number of ways in which the CEID provides engineering design opportunities to

ME students. (See Appendix E for the schedule of events hosted by the CEID during the Academic Year 2019–2020.) First, the CEID provides not-for-credit training in machining, laser cutting, rapid-prototyping, data acquisition methods, microprocessor programming, and many other manufacturing, experimentation, and design techniques. After receiving training, students can use the equipment in the CEID for course projects and extracurricular activities. The CEID employs two full-time Ph.D.-level (Physics and Biomedical Engineering) design guides, two full-time B.S.-level design fellows, and undergraduate aides to field questions about the equipment and design process.

Second, the CEID summer fellowship program helps successful student applicants to pursue their engineering design ideas. During this summer fellowship, teams of students are supported to pursue their own design inquiries. In 2019, the CEID supported eight students on three design teams, and in 2020 the CEID is supporting 11 students on five design teams. It is not uncommon for students to continue their summer work during the school year, with some of the projects leading to inventions and start-ups. In 2020, the five teams of CEID summer fellowship students were involved in projects that included museum exhibits, Cube-Sats, automated food preparation, air flow for face shields, and touchscreen display systems. This ten-week immersive experience is a significant interdisciplinary engineering design and building experience available to SEAS students.

Third, the CEID hosts and mentors undergraduate organizations dedicated to engineering projects. The undergraduate student engineering groups include Bulldogs Racing (Yale's champion Formula Hybrid racecar team); the Yale Undergraduate Aerospace Association, which builds and flies model rockets, airplanes, and quadcopters; Yale Robotics, which designs and builds robots for intercollegiate competitions; Design for America, which teams students together to solve local design challenges to improve the community; and Engineers without Borders, which has worked on projects for over a decade to supply villages in Cameroon and Tanzania with safe drinking water. In addition to these examples, other engineering associations are supported by the CEID, thereby demonstrating its value in promoting a culture for engineering at Yale.

Cooperative education:

The Mechanical Engineering Program at Yale does not allow cooperative education to satisfy curricular requirements. However, engineers from industry (or other universities) can serve as co-advisors on independent study projects for course credit in MENG 471, 472, 473, or 474. The student must also be co-advised by a Yale faculty member, Ph.D.-level CEID staff member, or lecturer.

Materials available for review during the campus visit:

The Mechanical Engineering Program will provide the following curricular materials for the review visit: 1) course materials including the syllabus, all assignments and exams and three examples of student work (exemplary, satisfactory, and unsatisfactory); 2) the general institution catalog (i.e., the Yale College Programs of Study); 3) promotional brochures describing the offerings of the School of Engineering & Applied Science; and 4) official academic transcripts of all Program graduates. Additional review materials concerning continuous improvement of Student Outcomes attainment are described in Chapter 4.

B. Course Syllabi

Appendix A includes 54 course syllabi for the 15 required courses, 32 possible elective courses (from which students select four), and nine prerequisite courses in mathematics, physics, and chemistry.

CRITERION 6. FACULTY

A. Faculty Qualifications

The number of faculty in the Department of Mechanical Engineering and Materials Science (MEMS) is sufficient for achieving the Program Educational Objectives. MEMS consists of 13.5 full-time ladder faculty members (8.5 senior and 5 junior): Charles Ahn, Aaron Dollar, Juan Fernandez de la Mora, Alessandro Gomez, Marshall Long, Corey O'Hern, Jan Schroers, Udo Schwarz, and Mitchell Smooke are senior, and Eric Brown, Judy Cha, Rebecca Kramer-Bottiglio, Diana Qiu, and Madhusudhan Venkadesan are junior. (Charles Ahn's appointment is split equally between the MEMS and Applied Physics Departments.) Each faculty member (except the Department Chair, Udo Schwarz, who has Chair teaching relief of 1 course per year) has a teaching load of one course per term, which provides a maximum level of teaching coverage of 26 courses per year. Several of the MEMS faculty have won prestigious teaching awards from the University including Professors Smooke, O'Hern, and Venkadesan. Professor Smooke won the Dylan Hixon '88 Prize for Teaching Excellence in the Natural Sciences and also the Sheffield Teaching Award; Professor O'Hern won the SEAS Ackerman Teaching and Mentoring Award; and Professor Venkadesan won the Poorvu Family Award for Excellence in Interdisciplinary Teaching.

In addition to the ladder faculty, the Department has a number of teaching faculty that support instruction for the Mechanical Engineering Program. First, MEMS has two full-time lecturers, Dr. Beth Anne Bennett and Dr. Joran Booth, on long-term contracts, who teach two courses per term and are supported by the School of Engineering & Applied Science and Office of the Provost. (See Chapter 8.B for information concerning funding of the two full-time lecturers.)

Dr. Bennett earned her Ph.D. in Mechanical Engineering from Yale in 1997, specializing in the development of adaptive computational techniques for efficient simulation of steady combustion applications in two dimensions. She was subsequently a postdoc at Yale in Mechanical Engineering and then stayed at Yale as an Associate Research Scientist, then as a Research Scientist, and finally as a Senior Research Scientist, extending her work on adaptive computational techniques to time-dependent moving front problems in combustion and solidification. During her years of research, Dr. Bennett also spent part of her time teaching, holding a co-appointment as a Lecturer starting in 1998. In 2015 she switched to full-time teaching. During her more than 20 years of teaching at Yale, Dr. Bennett has taught Applied Numerical Methods for Algebraic Systems, Eigensystems, and Function Approximation (MENG 440); Applied Numerical Methods for Differential Equations (MENG 441); Special Projects I and II (MENG 471, MENG 472, MENG 473, and MENG 474); Mechanical Design: Process and Implementation (MENG 487L/MENG 488L [co-taught]); and Introduction to Materials Science (MENG 285). She has also taught courses in Engineering & Applied Science: Multivariable Calculus for Engineers (ENAS 151); Ordinary and Partial Differential Equations with Applications (ENAS 194); and Introduction to Computing for Engineers and Scientists (ENAS 130); as well as Calculus of Functions of One Variable II (MATH 115). During her time at Yale, Dr. Bennett has served as the faculty adviser for several undergraduate engineering student groups, e.g. ASME and Tau Beta Pi, and has mentored undergraduates participating in regional, national, and international engineering competitions. Dr. Bennett is currently a sophomore adviser for students interested in majoring in Mechanical Engineering.

Dr. Booth received his Ph.D. from Purdue University in Mechanical Engineering in 2016, specializing in early design theory and design for additive manufacturing. Following his Ph.D., Dr. Booth worked as a postdoc for Prof. Kramer-Bottiglio at Purdue University, and he moved to Yale with the laboratory in 2017. He specializes in system design of soft robots and still maintains research connections with design for additive manufacturing and design theory and methodology. Prior to teaching at Yale, Dr. Booth taught as a head teaching assistant, laboratory coordinator, and instructor at Purdue University during his Ph.D., teaching entrepreneurship and machine design. For his work at Purdue, he was awarded several teaching awards and a year-long teaching fellowship. Dr. Booth started at Yale in 2018 as a lecturer and research scientist, teaching Machine Elements and Manufacturing Processes (MENG 325), Special Projects I (MENG 471 and MENG 472), and the capstone sequence, Mechanical Design: Process and Implementation I and II (MENG 487L and MENG 488L). Dr. Booth has also served as a faculty adviser for undergraduate students taking Special Projects I and II and is a Fellow of Berkeley College.

In addition, the CEID has two full-time staff members, Dr. Lawrence Wilen and Dr. Joseph Zinter, who frequently teach engineering design courses, such as ENAS 118 (Introduction to Engineering, Innovation, and Design), ENAS 400 (Making It: Product Design and Entrepreneurship), and ENAS 410 (Making Spaces). Furthermore, two clinical faculty from the Yale School of Medicine, Dr. Steven Tommasini and Daniel Wiznia, teach MENG 404 (Medical Device Design and Innovation), which is a popular design elective.; Dr. Wiznia has a secondary appointment in MEMS.

Senior faculty members receive teaching relief for one semester after teaching one course in each of six consecutive semesters, and junior faculty members receive teaching relief for one full year during their first (Years 1–2) and second term (Years 2–4) appointments. To cover courses required for the Mechanical Engineering Program when faculty are on teaching leave, the Department hires several adjunct teaching faculty. (See Chapter 8.B for information concerning funding of non-ladder faculty.) In Academic Year 2019–2020, the adjunct teaching faculty were Dr. Ronald Adrezin, Dr. Sudhangshu Bose, Mr. Ronald Lehrach, and Dr. Alex Tsai. Drs. Adrezin and Tsai are members of the faculty in the Department of Mechanical Engineering at the United States Coast Guard Academy. Dr. Bose worked at Pratt and Whiney as an engineer for over 30 years and has taught at Rensselaer Polytechnic Institute, and Mr. Lehrach worked at United Technologies Research Center as an engineer for nearly 25 years and has taught at Yale since 2008. The adjunct teaching faculty are excellent teachers and mentors and are vetted by the Program Chair and DUS. Several additional faculty members from the Departments of Biomedical Engineering, Chemical Engineering, Electrical Engineering, Mathematics, Physics, Chemistry, Computer Science, Geology & Geophysics, and Statistics & Data Science teach the prerequisite courses, electives, and some required courses. Resumes of the Department faculty, full-time lecturers, non-ladder teaching faculty, and the faculty members from other departments who teach courses in the Mechanical Engineering Program are included in Appendix B.

The student-to-faculty ratios for all graduating Mechanical Engineering majors in the past three years (from 2018 to 2020) were 2.74, 3.56, and 2.89. For ABET program majors, these ratios were 1.11, 1.85, and 1.26. These ratios are lower than most private and state universities with similar missions and Program Educational Objectives. For example, the ratios for UC Berkeley, University of Michigan, University of Illinois at Urbana-Champaign, and UC San Diego were 4.20, 3.88, 3.50, and 3.53 in 2018, respectively. A benefit of Yale's low student-to-faculty ratio is that the Mechanical Engineering classes are small with significant faculty and student interactions.

The MEMS ladder faculty members received their Ph.D.s and performed postdoctoral research training at top peer institutions including Harvard, Stanford, University of Pennsylvania, Princeton, Cornell, Massachusetts Institute of Technology, and California Institute of Technology. All of the faculty members are research active with ongoing federal and/or industrial funding for research. The MEMS ladder faculty have received numerous professional awards including the Alfred P. Sloan Fellowship (Ahn), David and Lucile Packard Fellowship in Science and Engineering (Ahn), National Science Foundation (NSF) CAREER Award (Ahn, Brown, Cha, Dollar, Gomez, Kramer-Bottiglio, O'Hern), NASA Early Career Faculty Award (Dollar, Kramer-Bottiglio), NSF Presidential Early Career Award for Scientists and Engineers (PECASE) (Kramer-Bottiglio, Long), DARPA Young Faculty Award (Dollar), Office of Naval Research (ONR) Young Investigator Award (Kramer-Bottiglio), Air Force Office of Scientific Research (AFOSR) Young Investigator Award (Dollar, Kramer-Bottiglio), Technology Review's "35 Young Innovators Under 35" (Dollar), and Forbes's "30 Under 30" (Kramer-Bottiglio). Additionally, various MEMS ladder faculty members have received the prestigious recognition of being named a Fellow of the following bodies: Connecticut Academy of Science and Engineering (Ahn, Fernandez de la Mora, Gomez, Long, Smooke), Connecticut Academy of Arts and Sciences (Fernandez de la Mora), European Union Academy of Sciences (Gomez), American Association for the Advancement of Science (AAAS) (Ahn), American Physical Society (Ahn, O'Hern), Materials Research Society (Ahn), American Institute of Aeronautics and Astronautics (AIAA) (Smooke), Society of Industrial and Applied Mathematics (SIAM) (Smooke), Institute of Physics (IOP) (Smooke), and the Combustion Institute (Gomez, Long, Smooke).

The research expertise of the MEMS faculty spans the disciplines of Mechanical Engineering and Materials Science. The broad research areas can be categorized as "Fluid and Thermal Sciences," "Materials," and "Robotics and Mechatronics," although there is significant crossover among these research areas. The research subfields in the general area of "Fluids" include turbulence (Brown), combustion (Gomez), flame visualization (Long), computational fluid dynamics (Smooke), and electrosprays (Fernandez de la Mora, Gomez). The "Materials" group includes research in metal oxides (Ahn), theoretical studies of quantum materials (Qiu), nanomaterials (Cha), scanning force microscopy and nanotribology (Schwarz), soft matter and complex fluids (Brown, O'Hern), and bulk metallic glasses (Schroers). The "Robotics" group focuses on robotic grasping and manipulation (Dollar), soft robotics (Kramer-Bottiglio), and evolutionary biomechanics (Venkadesan). Three of the faculty perform theoretical and computational studies (O'Hern, Qiu, and Smooke), and the remaining faculty are experimentalists. The expertise of the MEMS faculty covers all of the "Engineering Topics" courses described in Chapter 5.A.

The years of experience and levels of activity in professional organizations, professional development activities, and consulting for the Program faculty are provided in Table 6-1, which appears on the next two pages. The average teaching experience is 18 years. The average level of activity in professional organizations and professional development is between medium to high.

Table 6-1. Faculty Qualifications.

Mechanical Engineering

Faculty Name	Highest Degree Earned, Field, and Year	Rank [1]	Type of Academic Appt.[2] T, TT, NTT	FT or PT[3]	Years of Experience			Professional Registration/ Certification	Level of Activity[4] H, M, or L		
					Govt./Ind. Practice	Teaching	This Institution		Professional Organizations	Professional Development	Consulting/summer work in industry
Yale Mechanical Engineering Ladder Faculty											
Udo Schwarz (Chair)	Ph.D., Physics, 1993	P	T	FT	0	27	18	N/A	M	H	L
Charles Ahn	Ph.D., Applied Physics, 1996	P	T	FT	0	20	20	N/A	M	M	L
Juan Fernandez de la Mora	Ph.D., Eng. & Applied Science, 1981	P	T	FT	0	39	39	N/A	M	H	H
Aaron Dollar	Ph.D., Engineering Sciences, 2007	P	T	FT	1	11	11	N/A	M	H	L
Alessandro Gomez	Ph.D., Mech. & Aerospace Eng., 1986	P	T	FT	0	32	32	N/A	L	H	M
Marshall Long	Ph.D., Physics, 1980	P	T	FT	0	40	40	N/A	M	L	L
Corey O'Hern (DUS)	Ph.D., Physics, 1999	P	T	FT	0	18	18	N/A	M	H	L
Jan Schroers	Ph.D., Physics, 1997	P	T	FT	4	14	14	N/A	M	M	H
Mitchell Smooke	Ph.D., Applied Mathematics, 1979	P	T	FT	6	36	36	N/A	H	L	L
Judy Cha	Ph.D., Physics, 2009	ASC	TT	FT	0	7	7	N/A	H	H	L
Eric Brown	Ph.D., Physics, 2007	AST	TT	FT	0	9	7	N/A	M	L	L
Rebecca Kramer-Bottiglio	Ph.D., Engineering Sciences, 2012	AST	TT	FT	0	7	3	N/A	H	H	L
Diana Qiu	Ph.D., Physics, 2017	AST	TT	FT	0	0.5	0.5	N/A	M	M	L
Madhusudhan Venkadesan	Ph.D., Mech. & Aerospace Eng., 2007	AST	TT	FT	0	5	5	N/A	H	H	L

Yale Mechanical Engineering Teaching Faculty											
Beth Anne Bennett	Ph.D., Mechanical Engineering, 1997	I	NTT	FT	0	22	22	N/A	H	M	L
Joran Booth	Ph.D., Mechanical Engineering, 2016	I	NTT	FT	0.5	3	2	N/A	M	M	L
Lawrence Wilen	Ph.D., Physics, 1986	I	NTT	FT	9	14	5	N/A	L	M	L
Joseph Zinter	Ph.D., Biomedical Engineering, 2011	I	NTT	FT	1	9	8	N/A	L	M	L
Adjunct Mechanical Engineering Teaching Faculty											
Ronald Adrezin	Ph.D., Mechanical Engineering, 1997	A	NTT	PT	8	28	1	PE	L	H	M
Sudhangshu Bose	Ph.D., Materials Science & Eng., 1978	A	NTT	PT	30	19	3	N/A	L	L	H
Ronald Lehrach	M.S., Mechanical Engineering, 1965	A	NTT	PT	43	12	12	N/A	L	L	L
Alex Tsai	Ph.D., Mechanical Engineering, 2007	A	NTT	PT	9	9	2	PE	L	M	L
Yale Ladder Faculty in Other Departments											
Daniel Wiznia	M.D., Orthopedic Surgery, 2012	AST	TT	FT	0	2	2	N/A	H	M	M
Yale Teaching Faculty in Other Departments											
Steven Tommasini	Ph.D., Biomedical Engineering, 2008	I	NTT	FT	0	9	9	N/A	M	M	L

Instructions: Complete table for each member of the faculty in the program. Add additional rows or use additional sheets if necessary. Updated information is to be provided at the time of the visit.

1. Code: P = Professor ASC = Associate Professor on Term AST = Assistant Professor I = Instructor A = Adjunct O = Other
2. Code: TT = Tenure Track T = Tenured NTT = Non Tenure Track
3. At the institution
4. The level of activity, high, medium or low, should reflect an average over the year prior to the visit plus the two previous years.

B. Faculty Workload

Table 6-2, which appears on the next four pages, details all courses that have been taught by MEMS ladder faculty, MEMS teaching faculty, and adjunct faculty during Academic Year 2019–2020. With the exception of Prof. Corey O'Hern, we see that each ladder faculty member teaches no more than two courses per year: either one graduate course and one undergraduate course or two undergraduate courses, unless the faculty member is on leave. O'Hern is the Director of the NIH-supported Integrated Graduate Program in Physical and Engineering Biology (PEB). As a result, he often teaches 1.5 course credits for the PEB program in addition to 2.0 course credits for the Mechanical Engineering Program. Table 6-2 also lists the teaching and research activity percentages for each faculty member and non-ladder teaching faculty, as well as the percentage of time devoted to the Mechanical Engineering Program during the time that the faculty member has been at Yale. The average teaching and research activity percentages for MEMS ladder faculty are 35% and 60%, respectively, with an average of 5% of effort devoted to other activities (such as consulting and administrative service). Also, faculty teaching effort is typically devoted to the Mechanical Engineering Program, unless the faculty member is on leave or teaching a graduate course.

Table 6-2. Faculty Workload Summary.

Mechanical Engineering

Faculty Name	FT or PT[1]	Classes Taught (Course No./Credit Hrs.) (All courses are 1 course credit except for MENG 286L, MENG 487L, and MENG 488L, each of which is 0.5 course credits.)	Term[6]	Year[2]	Program Activity Distribution[3]			% of Time Devoted to the Program[5]
					Teaching	Research or Scholarship	Other[4]	
Yale Mechanical Engineering Ladder Faculty								
Udo Schwarz (Chair)	FT	MENG 464/ENAS 787: Forces on the Nanoscale	SP	2020	25%	50%	25% (Chair); Teaching Leave F2019	100%
Charles Ahn	FT	None			0%	100%	Teaching Leave F2019, SP2020	50%
Juan Fernandez de la Mora	FT	MENG 469: Aerodynamics	F	2019	25%	75%	Leave SP2020	100%
Aaron Dollar	FT	ENAS 778: Advanced Robotic Mechanisms	F	2019	50%	50%	0%	100%
		MENG 185: Mechanical Design	SP	2020				
Alessandro Gomez	FT	MENG 361: Mech. Eng. II: Fluid Mechanics	F	2019	50%	40%	10% (Fac. Senate)	100%
		MENG 363L: Fluid Mechanics and Thermo. Lab.	SP	2020				
Marshall Long	FT	MENG 400/ENAS 600: Computer-Aided Engineering	F	2019	25%	25%	50% (Phased Retirement) SP2020	100%

Corey O'Hern (DUS)	FT	ENAS 991/MB&B 591/MCDB 591: Integrated Workshop	F	2019	50%	50%	0%	100%
		MB&B 520: Boot Camp Biology						
		MENG 472: Special Projects I	SP	2020				
		MENG 474: Special Projects II						
		ENAS 517/MB&B 517/MCDB 517/PHYS 517: Methods and Logic in Interdisciplinary Research						
		PHYS 099: Introduction to Research Methods in Physics & Biology: Preparing for a First Research Experience						
Jan Schroers	FT	MENG 286L: Solid Mechanics and Materials Science Laboratory	F	2019	50%	50%	0%	100%
		MENG 286L: Solid Mechanics and Materials Science Laboratory	SP	2020				
Mitchell Smooke	FT	ENAS 194/APHY 194: Ordinary and Partial Differential Equations with Applications	F	2019	25%	75%	Leave SP2020	100%
Judy Cha	FT	None			0%	100%	Leave F2019, SP2020	100%
Eric Brown	FT	MENG 280: Mech. Eng. I: Strength and Deformation of Mechanical Elements	F	2019	50%	50%	0%	100%
		ENAS 848/PHYS 528: Soft Matter Condensed Physics	SP	2020				
Rebecca Kramer-Bottiglio	FT	MENG 185: Mechanical Design	F	2019	25%	75%	Leave SP2020	100%
Diana Qiu	FT	MENG 211: Thermodynamics for Mechanical Engineers	SP	2020	50%	50%	Hired Jan. 2020	100%
Madhusudhan Venkadesan	FT	MENG 459/BENG 459/ENAS 559: Neuromuscular Biomechanics	F	2019	50%	50%	0%	100%
		MENG 390/ENAS 994: Mechatronics Laboratory	SP	2020				

Yale Mechanical Engineering Teaching Faculty								
Beth Anne Bennett	FT	MENG 441/ENAS 441/ENAS 748: Applied Numerical Methods for Differential Equations	F	2019	100%	0%	0%	100%
		ENAS 130: Introduction to Computing for Engineers and Scientists						
		ENAS 151/APHY 151/PHYS 151: Multivariable Calculus for Engineers	SP	2020				
		ENAS 194/APHY 194: Ordinary and Differential Equations with Applications						
Joran Booth	FT	MENG 471: Special Projects I	F	2019	67%	33%	0%	100%
		MENG 487L: Mechanical Design: Process and Implementation I						
		MENG 325: Machine Elements and Manufacturing Processes	SP	2020				
		MENG 488L: Mechanical Design: Process and Implementation II						
Lawrence Wilen	FT	ENAS 118: Introduction to Engineering, Innovation, and Design	F	2019	13%	12%	75% (Design Mentor, CEID)	13%
Joseph Zinter	FT	ENAS 400: Making It: Product Design and Entrepreneurship	F	2019	25%	0%	75% (Asst. Director, CEID)	25%
Adjunct Mechanical Engineering Teaching Faculty								
Ronald Adrezin	PT	MENG 389: Mech. Eng. IV: Fluid and Thermal Energy Science	SP	2020	100%	0%	0%	20%
		MENG 400/ENAS 600: Computer-Aided Engineering						
Sudhangshu Bose	PT	MENG 285: Introduction to Materials Science	F	2019	100%	0%	0%	100% (Retired)

Ronald Lehrach	PT	MENG 365: Chemical Propulsion Systems	SP	2020	100%	0%	0%	100% (Retired)
Alex Tsai	PT	MENG 383: Mech. Eng. III: Dynamics	F	2019	100%	0%	0%	12%
Yale Ladder Faculty in Other Departments								
Daniel Wiznia	FT	MENG 404/BENG 404: Medical Device Design and Innovation	SP	2020	13%	37%	50% (Clinical)	13%
Yale Teaching Faculty in Other Departments								
Steven Tommasini	FT	MENG 404/BENG 404: Medical Device Design and Innovation	SP	2020	13%	87%	0%	13%

1. FT = Full Time Faculty or PT = Part Time Faculty, at the institution
2. For the academic year for which the Self-Study Report is being prepared (2019–2020)
3. Program activity distribution should be in percent of effort in the program and should total 100%.
4. Indicate sabbatical leave, etc., under "Other."
5. Out of the total time employed at the institution.
6. F = Fall Term, SP = Spring Term

Note that courses with course listings greater than 500 are graduate courses.

C. Faculty Size

The current size of the MEMS Department is 13.5 ladder faculty members, including one faculty member (Qiu) who just arrived in January 2020. The Department had an active search in the area of Robotics and Mechatronics just prior to the pandemic, but the University has since suspended all faculty searches and hiring in light of the economic downturn. At the current faculty size for MEMS and given Yale's faculty leave policies, we typically need the equivalent of three full-time non-ladder teaching faculty (in addition to two full-time lecturers, Bennett and Booth) to offer the ME Program required courses.

As described in Chapter 1.D, several types of academic advisers are available to undergraduates. In this section, we focus mainly on advising related to the ME program. After the first year, the ME DUS is the principal academic advisor for each student majoring in Mechanical Engineering. Each semester, the DUS meets with each Mechanical Engineering student (typically ~40 per class) to discuss course schedules, plan the student’s path through the curriculum, research and industrial internship opportunities, and professional goals. The DUS also writes letters of recommendation for fellowship and study-abroad programs, graduate school, and summer research experiences for at least 15 students per year. As the number of ME majors continues to increase, the ME Department will distribute the undergraduate advising among several faculty members.

In the senior year, the capstone design project for Mechanical Engineering majors is carried out in the required two-semester course sequence, MENG 487L and 488L, which is supervised by Dr. Joran Booth. Mechanical Engineering majors (both ABET-accredited majors and Engineering Sciences-Mechanical majors) can also take either MENG 471 (in the fall) or MENG 472 (in the spring) as an elective towards the Mechanical Engineering degree. This course — Special Projects — is an independent research or mechanical design project advised by a Yale faculty member or lecturer. As an example, in Academic Year 2019–2020, the following faculty members mentored students, with the number mentored given in parentheses: Booth (1), Brown (2), Kramer-Bottiglio (2), O’Hern (1), Schroers (1), Venkadesan (2), and Wiznia (3). Similar shared responsibility for advising the Special Projects courses occurred in previous years. Example descriptions of the Special Projects course projects are provided at: https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-472474-projects-2020 and https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-471473-projects-2019.

Several of the MEMS ladder faculty members are actively involved with university service, such as the Faculty Senate (Gomez), Advisory Committee of the Yale Energy Science Institute (Schwarz), Chair of the University-wide Shop Safety Committee (Dollar), Course of Study Committee (Venkadesan), Committee on Majors (O’Hern), Science Scholars Awards Committee (O’Hern), faculty search committees, and other university committees, but these duties do not interfere with participation in the ME Program.

Several of the faculty members have also cultivated close relationships with industrial partners including Profs. Fernandez de la Mora (NanoEngineering, SEADM, CARTIF, Kanomax), Kramer-Bottiglio (Intel, Otherlab), O'Hern (Facebook, Schlumberger), Schroers (Materion, Desktop Metal, Supercool Metals, Patek Philippe), Schwarz (Scienta Omicron GmbH), and Wiznia (Stryker Orthopedics, Zimmer Biomet, Intellijoint Surgical). The CEID, in cooperation with the Office of Career Strategy, also frequently invites company representatives to Yale for career fairs. Entrepreneurs and leaders of industries, such as Disney Imagineering CEO Kareem Daniel, astronaut Chris Cassidy, and Fitbit founder Eric Friedman have been invited to campus in the past several years to discuss possible career paths for engineering graduates.

D. Professional Development

The professional development activities of the ME Program ladder faculty include peer review of articles in archival journals and grant proposals; (co-)organizing workshops, conferences, symposia, and seminar series; (co-)chairing technical sessions at national and international conferences; serving as external reviewers for national laboratories and computing centers; serving on engineering advisory boards for other universities; and speaking at public outreach events for middle school students, high school students, and the general public. Many faculty members are — or within the past two years have been — Associate Editors of archival journals (Dollar, Kramer-Bottiglio [three journals], Schwarz, and Venkadesan), members of Editorial/Advisory Boards of journals (Ahn [two journals], Cha, Kramer-Bottiglio, and Long), Co-Editor-in-Chief of a journal (Smooke), and editors for special topical issues of journals. Smooke is a member of the Board of Directors of the Combustion Institute, which is the primary professional society in the field of combustion. All faculty regularly give invited talks at national and international technical meetings. More details concerning the professional development activities for the MEMS faculty can be found in Appendix B.

E. Authority and Responsibility of Faculty

In this section, the processes involved in (a) course creation and modification, (b) definition and revision of Program Educational Objectives (PEOs) and Student Outcomes (SOs), and (c) course evaluation will be described. The process involved in deciding whether to create new or modify existing courses, PEOs, and SOs involves a cooperative decision-making process that includes several constituencies. The decision-making process for revising the PEOs was described in detail in Chapter 2.E. A similar process is carried out when determining whether courses and SOs should be added or changed, as was described in detail in Chapter 4. These processes are now briefly reviewed.

Proposals for new courses and changes to existing courses are initiated by the instructor of record in the web-based curriculum management tool, CourseLeaf. The DUS is responsible for verifying that the details of the course are accurately described on the web form, describing the importance of the course for the Mechanical Engineering Program, and electronically submitting the proposal to Yale College's Course of Study Committee. This Committee reviews the course for consistency with Yale's academic policies, with the Yale College Faculty then voting on changes at monthly faculty meetings. The DUS and Committee iterate on any changes required for the new or altered course to be accepted.

The key to the success of the Committee's work is the care and clarity with which DUS propose new courses or changes to existing courses. Obviously the members of the committee cannot be experts in all fields of instruction; they must place great trust in the thoroughness and diligence of the DUS, whose approval is taken as representing the considered judgment of the Department. Therefore, in the event that the DUS is the instructor of the proposed course, the Chair of the department or program should submit the Course Proposal Form (and, conversely, the DUS should submit the form if the Chair is the instructor).

Regarding the Program Educational Objectives and Student Outcomes, once a decision has been made to change any of them, the DUS requests the appropriate changes in the copy in the Yale College Programs of Study (YCPS) and on the MEMS website. Changes made in the YCPS automatically propagate to the Yale Course Search website (courses.yale.edu).

To assist instructors in improving their courses and their teaching, Yale College encourages students to participate in a college-wide system of course evaluation for all courses in which they enroll. Students must complete, or actively decline to complete, online evaluations for their courses to obtain early access to online reports of term grades from the Registrar's Office. Student feedback from the online course evaluations is forwarded to the instructor of record and the Department Chair. The Chair discusses the course evaluations with instructors on a yearly basis. The online evaluations ask the following questions:

1. What knowledge, skills, and insights did you develop by taking this course?
2. Your level of engagement with the course was: (1-very low, 2-low, 3-medium, 4-high, 5-very high).
3. What are the strengths and weaknesses of this course and how could it be improved?
4. What is your overall assessment of this course? (1-poor, 2-fair, 3-good, 4-very good, 5-excellent)
5. The course was well organized to facilitate student learning. (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree)
6. I received clear feedback that improved my learning. (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree)
7. Relative to other courses you have taken at Yale, the level of intellectual challenge of this course was: (1-much less, 2-less, 3-same, 4-greater, 5-much greater).
8. Relative to other courses you have taken at Yale, the workload of this course was: (1-much less, 2-less, 3-same, 4-greater, 5-much greater).
9. Would you recommend this course to another student? Please explain.
10. Summarize the strengths and weakness of the instructor. In what ways was their teaching effective and in what ways could their teaching be improved?

Due to the switch to remote learning in March 2020, the course evaluation questions for the Spring 2020 semester were modified by Yale College to become the following:

1. What knowledge, skills, and insights did you develop by taking this course?
2. For the period on campus before remote learning, what actions did you take that helped your learning in this course?

3. For the period of remote learning, what actions did you take that helped your learning in this course?
4. For the period on campus before remote learning, in what ways was the instructor effective and in what ways could the teaching be improved?
5. For the period of remote learning, what strategies did your instructor use that were helpful?

The MEMS faculty play a critical role in attaining Student Outcomes as described in Chapter 4. MEMS faculty use a variety of methods to assess the attainment of Student Outcomes including “The Yale Method”. This method is embedded in a user-friendly Excel spreadsheet, where faculty use their own grading system to track results of student performance. In this spreadsheet, faculty input grades for each assignment (exams, homework, and other coursework), and assign a corresponding weighting factor and a fractional component of the Student Outcomes associated with each particular assignment.

This spreadsheet also yields the breakdown of student performance (unsatisfactory, acceptable, and exemplary) per assignment based on the faculty’s input for the cutoff percentages. The spreadsheet then calculates a grade for each student and the percent of each ABET Student Outcome that is achieved by this course. Finally, the spreadsheet produces a graph and a table that clearly shows the levels of performance for each ABET outcome that is assessed in the course. The analysis of each single course is then combined with the same analysis from all other courses in the curriculum to establish an overall measure of the program’s ability to achieve particular Student Outcomes. These results illustrate the contributions at the course and program levels for each Student Outcome to quantify the range of performance and serve as a tool for continuous improvement.

As noted in Chapter 4, this method of outcomes assessment is accompanied by a series of other Student Outcomes assessment methods including graduating senior interviews and three independent review methods within the capstone design course. Collectively these methods engage a large number of faculty in a variety of outcomes assessment methodologies.

It is important to note that the Program Faculty are directly responsible for continuously improving Yale’s Mechanical Engineering Program, and they have the authority to implement changes. While financial and infrastructural support are provided by the Offices of the Dean and Provost, the direction of the Program is at the discretion of the MEMS Faculty. Several examples from 2014 through 2020 of continuous improvement initiated and enacted by the Program Faculty can be found Sections A and B of Chapter 4.

CRITERION 7. FACILITIES

A. Offices, Classrooms, and Laboratories

Not only has the School of Engineering & Applied Science (SEAS) succeeded in attracting top faculty, but it also seeks only the best in research, administrative, and technical staff — all dedicated to furthering the excellence of the research and teaching in SEAS. The SEAS Dean's Office is located in "17 Hillhouse" Room 105. Its staff is composed of 14 employees (including the Dean, Deputy Dean, and Assistant Dean), all working together to support students and faculty in their academic affairs. They coordinate School-wide functions such as communications and admissions, assist undergraduate students with their extra-curricular activities (e.g. undergraduate student groups), provide financial support and financial administration, and guide students concerning safety and content relevant to projects associated with their academic paths.

Faculty in the Department of Mechanical Engineering & Materials Science are all provided with an office in either Becton Engineering Center or Mason Laboratory; the only exceptions are Profs. Venkadesan and Qiu, whose offices are located in 17 Hillhouse and the West Campus Energy Institute, respectively. In addition, Program Faculty are supplied with space for experimental and computational research laboratories in Becton Engineering Center (Profs. Ahn, Long, Smooke, Schroers, Schwarz), Mason Laboratory (Profs. Fernandez de la Mora, Dollar, Kramer-Bottiglio, Gomez, O'Hern), Dunham Laboratory (Prof. Brown), Malone Laboratory (Prof. Schwarz), 17 Hillhouse (Prof. Venkadesan), and the West Campus Energy Institute (Profs. Cha and Qiu).

The Department of Mechanical Engineering & Materials Science is supported by three administrative assistants. Mary MacNicholl and Janet O'Dell are located in Becton Engineering Center Rooms 203 and 211, respectively, and Leslie Radcliffe is located in Mason Laboratory Room M11. These individuals assist in supporting the Faculty's administrative needs, including academic recordkeeping and student payroll (for Program students working at Yale). The offices of the administrative assistants are equipped with fax machines, copiers, and scanners for faculty use. In addition, there is a color HP plotter printer in the common area of the Dean's Office for faculty and students to print posters for projects, activities, and presentations.

Teaching Fellows for undergraduate courses are provided with workspace associated with their research laboratories. While some of the spaces are within the laboratories, the majority are external offices that house a number of graduate students.

In addition to SEAS resources, engineering faculty have access to Yale-wide resources to advance teaching skills. Yale established the Poorvu Center for Teaching and Learning in 2017 to improve teaching, support engaged learning, and centrally locate education resources and support for the Yale community. As a modern, open, and inviting 24,000-square-foot facility, the Center has flourished as the university's preeminent hub for teaching and learning and represents a new era in Yale's commitment to pedagogical excellence. Of note was the very central role this

Center played in the abrupt transition to remote learning during the Spring 2020 semester, as well as the important guidance the Center's staff is providing to help faculty plan, facilitate and deliver online content in future courses.

General-purpose classrooms within the Yale School of Engineering & Applied Science

Yale College maintains classrooms throughout the campus to which SEAS has access as needed. Classrooms for which SEAS has direct control include two 20-seat classrooms (Becton Engineering Center Room 408 and Becton Engineering Center Room 508), a 25-seat classroom (Arthur K. Watson Hall Room 200), and one 20-seat seminar room (Mason Laboratory Room 107). Classrooms under the control of the Yale Registrar that are located in SEAS buildings include a 260-seat auditorium (Davies Auditorium in the Becton Engineering Center), a 100-seat classroom (Mason Laboratory Room 211), a 150-seat classroom (Dunham Laboratory Room 220), a 45-seat classroom (Becton Engineering Center Room CO31), a 30-seat classroom (Mason Laboratory Room 104), and a 25-seat classroom (Arthur K. Watson Hall Room 100). A 21-station computer classroom is located in Dunham Laboratory 120D, and a 52-station computer classroom is located in 17 Hillhouse.

Unique classrooms accessible to the Yale School of Engineering & Applied Science: Classrooms located in 17 Hillhouse

Six classrooms are located in the building that is officially called 17 Hillhouse (in the midst of the Yale SEAS concentration of buildings on Yale's campus bounded by Prospect St., Trumbull St., Hillhouse Ave., and Grove St.). This building was renovated in 2013 to improve and advance science and technology education at Yale. The building renovation converted the former medical facility into a modern teaching and research center, with classrooms, research laboratories, and faculty and student offices all housed in this building. The 17 Hillhouse classrooms encourage discussion and interaction among students in smaller classes and lectures alike, and include a 126-seat Technology Enabled Active Learning (TEAL) classroom where students sit at 9-person tables in a technology-rich environment. This classroom promotes active learning and enables technology (from the instructor and from each student) to be integrated into the lectures, demonstrations, and discussions. The facility is frequently used by the Mechanical Engineering program with the courses Mechanical Engineering IV: Fluid and Thermal Energy Science (MENG 389), Machine Elements and Manufacturing Processes (MENG 325), and Computer-Aided Engineering (MENG 400/ENAS 600) held in 17 Hillhouse classrooms.

Unique learning environments accessible to the Yale School of Engineering & Applied Science: Center for Engineering Innovation and Design (CEID)

Yale's Center for Engineering Innovation and Design (CEID) in the Becton Engineering Center helps catalyze Yale's design, innovation, and creativity initiatives. In operation since 2012, the CEID serves not only our own students but also the entire design community at Yale. The CEID's mission is to "empower its members to improve human lives through the advancement of technology. CEID aspires to launch high-impact projects and develop visionary leaders. It does so by bringing together people from diverse backgrounds and giving them resources to learn, create, and share."

Membership in the CEID provides 24/7 access to a functional facility that includes an open studio, workshops, meeting rooms, and an instructional area. Membership is open to all students, faculty, and staff at Yale. The studio is equipped with 3D printers, hand tools, electronics fabrication and testing equipment, and a variety of materials and components available to members at no charge. CEID members also have access to a state-of-the-art machine and metal shop, wood shop, and wet lab, as well as the assistance of four staff members (two Ph.D.-level, two B.S.-level) that manage all aspects of the CEID. The Director of the CEID is Deputy Dean Vincent Wilczynski, who devotes half of his time to this role.

The CEID sponsors a spectrum of formal and student-driven activities to educate its members, build community, catalyze new creative ventures, and support member-driven projects. CEID staff regularly teach academic courses including a hands-on freshman engineering course (ENAS 118), a course on the design of new products (ENAS 400), and a course on the design of musical instruments (ENAS 344). In addition, engineering faculty regularly team-teach design courses in the CEID on the design of biomedical devices (MENG 404, co-taught by MEMS and Biomedical Engineering faculty) and sustainable design (ENAS 360, co-taught by Environmental Engineering and Chemistry faculty). Beyond for-credit courses, CEID staff train students to use the facility's 3D printers, laser cutter, and machine tools.

In addition to this formal instruction, the CEID annually hosts more than 30 workshops on a variety of topics, such as building websites, making mathematical artwork with 3D printers, assembling electronic circuits, creating engineering portfolios, and microprocessor-based programming. The CEID also hosts lectures where speakers share their experiences in engineering, innovation, and design to inspire new projects, understand new trends in technology and the marketplace, and highlight potential career paths. In addition to these activities, the CEID regularly hosts social events to encourage networking and to foster a spirit of community, with these events including daily teas, evening study breaks, and an annual kick-off party to mark the start of a new academic year. (See Appendix E for the schedule of events for Academic Year 2019–2020.)

The CEID sponsors a summer fellowship program to support undergraduates in pursuit of their own design ideas. Fellows reside in the CEID for 10 weeks and receive mentoring and technical support from CEID staff in addition to stipends and professional development. The CEID is also a hub for student extracurricular activities. As examples, the Yale chapters of Design for America and Engineers Without Borders, the Yale Undergraduate Aerospace Association, and a number of student groups focused on robotics all use the CEID as their base of operation. The CEID is also a popular student destination for collaboration on class work, with students regularly meeting there to work on problem sets, study, and prepare for exams. In addition, each junior class of Mechanical Engineering majors has a group of 4–5 peer mentors, selected by the DUS for their academic success and participation in extracurricular activities, who hold study breaks and advising sessions for course selection for first- and second-year students in the CEID at least twice each semester.

The CEID staff actively collaborate with similar makerspace staff at other universities, both formally through the Higher Education Makerspace Initiative (a partnership of 8 universities who identify, vet, and disseminate best practices related to academic making) and informally with faculty and staff at other academic makerspaces. In October 2019, the CEID hosted the International Symposium on Academic Makerspaces to bring 350 members (from around the world) of this professional society together for three days of workshops, technical discussions, and fellowship.

Unique classrooms accessible to the Yale School of Engineering & Applied Science: CEID instructional area and meeting rooms

The CEID "instructional area" adjoins the open studio, with this instructional area serving four functions. Its first function is to hold classes. During Academic Year 2019–2020, classes held in the CEID instructional area included Making It: Product Design and Entrepreneurship (ENAS 400), Medical Device Design and Innovation (MENG 404), Introduction to Engineering Innovation and Design (ENAS 118), Musical Acoustics and Instrument Design (ENAS 344), and Green Engineering and Sustainable Design (ENAS 360). The openness of the instructional area in proximity to the studio space makes it an excellent venue for design courses, where students can learn the lecture material and readily put it into practice in the studio space.

The second function of the CEID instructional area is to serve as a space for guest lecture series and employment networking gatherings, typically scheduled on Monday evenings. The third use of this area is for CEID Workshop nights. Every Wednesday evening, the CEID staff has a workshop to enable students to explore and apply their creativity and academic knowledge for practical uses. The fourth use of the instructional area is for all other activities, such as student group meetings, social events, occasional symposia, and more. Any member can reserve the space, and it is available 24/7 with ID card swipe access for CEID members.

In addition to the instructional area, there are five reconfigurable conference rooms located on the mezzanine, each containing a computer with a large LCD screen and teleconference capabilities, along with plenty of whiteboard space. These rooms can also be used for classes in addition to meetings, small group discussions, student groups, and study time. The spaces can also be reserved online and are available 24/7 as well.

Teaching Laboratory Facilities relevant to the Yale Mechanical Engineering Program: Course Teaching Laboratories

A description of the Mechanical Engineering instructional laboratories is provided in Table 7-1. The facilities, with a footprint of more than 12,800 ft^2, include those associated with the Greenberg Engineering Teaching Concourse, Materials Laboratory and Mechanical Testing Facility, Fluid Mechanics and Thermodynamics Laboratory, and Mechanical Design Laboratory.

Table 7-1. Laboratory Facilities of the Department of Mechanical Engineering & Materials Science.

Physical Facilities (Building and Room Number)	Purpose of Laboratory (Courses Taught)	Laboratory Condition	Adequacy for Instruction	Number of Stations	Area (ft^2)
Linda and Glenn H. Greenberg Engineering Teaching Concourse (Dunham Laboratory)	Instructional laboratory for design, fabrication, electronics, capstone product development, and mechatronics (MENG 185, MENG 325, MENG 390, MENG 487L, MENG 488L)	Excellent	Excellent	56 equipment work stations for 112 students, work bench area for 24 students, plus 18 student spaces in 2 wet labs	10,000
Materials Laboratory (Becton 220/220A)	Materials characterization, mechanical testing, sample preparation (MENG 285, MENG 286L)	Excellent	Excellent	6 work stations	1,000
Mechanical Testing Facility (Becton 218)	Mechanical testing (MENG 280, MENG 285, MENG 286L)	Very good	Very good	4 work stations	1,000
Fluid Mechanics and Thermodynamics Laboratory (Mason B-7/B-5c Turbine Laboratory)	Instructional and research lab for fluid mechanics and thermodynamics (MENG 361, MENG 363L)	Adequate	Adequate	4 multi-user benches, 3 multi-user equipment-specific stations	800
Mechanical Design Laboratory (Mason B-7/B-8 Student Shop)	Instructional and research lab for mechanical design (MENG 185, MENG 487L, MENG 488L, MENG 471, MENG 472, MENG 473, MENG 474)	Adequate	Adequate	8 multi-user benches, 12 shop machine stations	1,000
					Total: 13,800

The **Linda and Glenn H. Greenberg Engineering Teaching Concourse** opened in 2017 as a central undergraduate teaching lab facility for all engineering majors. Spanning 10,000 square feet, the facility includes eight labs in total, including two wet labs with ventilation hoods and a tissue culture room. In addition, the concourse contains large lab preparation and storage rooms where course experiments can be developed in advance, stored for a period of time, and wheeled into the labs at the appropriate point in the semester. The space also includes an office for the School's Research and Teaching Support Staff (Mechanical Engineering Design Advisor Glenn Weston-Murphy, Electrical Engineering Design Advisor Kevin Ryan, and Research Scientist Katherine Schilling, Ph.D.).

The Teaching Concourse includes a single wide hallway that connects the floor-to-ceiling glass-walled labs (and the staff office) along both sides of the hallway. The openness and visibility of the space is intentional to promote learning, awareness, and safety. By centralizing engineering labs into one space, the Teaching Concourse encourages collaboration between students and faculty across all disciplines within engineering. A walk through the Teaching Concourse during lab instruction periods provides a window into each engineering discipline, thanks to the high visibility within the space. The facilities are exclusively used for academic courses.

Six dry labs range from 700 to 1,300 square feet and accommodate between 16 and 24 students in each lab with two students per lab station. Three of the labs are separated by folding doors (all of which are whiteboards) to enable these three labs to be used in alternate configurations. Three of the dry labs are outfitted with advanced electronics stations (computer, oscilloscope, power supply, function generator, and support tools, all described in more detail in Appendix C), while two other wet labs are equipped with the same collection of electronics (though at a more basic functional level). The fifth dry lab has a single electronics station to support periodic needs, with the lab workbenches generally left open to accommodate open-ended project courses and general lab instruction. The two wet labs are 550 and 650 square feet, with each lab having two hoods and a sink (including de-ionized water supply). One of the wet labs includes a tissue culture space. The wet labs can accommodate between 6 and 12 students, with these lab spaces used in tandem with a dry lab for course instruction.

Intentionally so, the labs are managed, scheduled, and staffed centrally by the SEAS Teaching Support staff to increase space utilization within the concourse. While specific lab assignments can change each semester, it is not uncommon for a particular lab to house multiple disciplines in a single semester, thereby helping meet the multidisciplinary intentions for the space. This $10M infrastructure investment, accompanied by outfitting the labs with $750K of new equipment including 60 new computers, electronic devices, experiment stations, and fabrication tools (detailed in Appendix C), demonstrate Yale's significant commitment of resources to support undergraduate engineering education.

The **Materials Laboratory and Mechanical Testing Facility** houses modern microscopy tools (optical-stereo microscope), materials testing instrumentation (tensile and hardness testers, micro and nanoindenters), and a differential scanning calorimeter. These facilities have more than 2000 ft^2 of dedicated space (Becton Engineering Center Rooms 218, 220, and 220A) to host laboratory exercises for the Solid Mechanics and Materials Science Laboratory (MENG 286L) course, as well as being capable of meeting the needs of any students doing materials-related investigations in Special Projects I (MENG 471 and MENG 472) and Special Projects II (MENG 473 and MENG 474). Becton Engineering Center Room 218 houses the mechanical testing apparatus. Room 220 houses the nanoindenter, and it will also house the helium pyncnometer as soon as it is installed. (Originally it was going to be installed in March 2020, but the installation has been delayed due to the pandemic.) Room 220A houses the arc melter and the metallographic polishing equipment. This equipment is described in greater detail in Appendix C.

The **Fluid Mechanics and Thermodynamics Laboratory** facilities include instrumentation that allow students to conduct experiments in fluid and thermal science and engineering and hosts students from Mechanical Engineering II: Fluid Mechanics (MENG 361), Fluid Mechanics and

Thermodynamics Laboratory (MENG 363L), Special Projects I (MENG 471 and MENG 472), and Special Projects II (MENG 473 and MENG 474). On the fluid mechanics side, the facilities include rheometers, viscometers, and tensiometers for measuring fluid properties, a rotating cylinder to study spin-up and spin-down of rotating fluids, and a subsonic wind tunnel that provides a platform for experiments ranging from boundary-layer characterizations to airfoil lift and drag measurements. Available instrumentation includes a variety of pressure probes and flow meters and a hot-film anemometry system from Dantec Dynamics. On the thermodynamics side, facilities include an oxygen bomb calorimeter, an internal combustion engine test stand, a fully instrumented turn-key gas turbine facility, an instrumented hydrogen fuel cell, and facilities for students to build and test simple dye-sensitized solar cells. Additional details concerning the equipment in the Fluid Mechanics and Thermodynamics Laboratory are provided in Appendix C.

The **Mechanical Design Laboratory**, which includes the **Student Shop**, is housed in Mason Laboratory Rooms B-7 and B-8. The equipment includes band saws, a belt/disc sander, drill presses, various types of sheet metal fabrication equipment, and a laser cutter. Laser cutters allow excellent “rapid prototyping” capabilities (with easy tie-ins to CAD models), and they use a range of inexpensive materials. Demo boards for electric and pneumatic actuators help students compare the pros and cons of various actuators easily, and the “inspiration shelf” contains partially disassembled or cut-away assemblies to inspire design ideation. In addition, there is a wide selection of hand tools and a large stockpile of mechanical parts, including bearings, motors, casters, gears, etc. Students have supervised access to the Laboratory after they complete a hands-on training and certification procedure with the SEAS Machine Shop Director. Additional details concerning the equipment in the Mechanical Design Laboratory and Student Shop are provided in Appendix C.

Teaching Laboratory Facilities relevant to the Yale Mechanical Engineering Program:
SEAS Machine Shop

The SEAS Machine Shop assists students, staff, and faculty conceive, design, and construct apparatus and instrumentation for the support of research and instructional projects. The SEAS Machine Shop equipment consists of basic machine shop tooling such as milling machines, lathes, band saws, drill presses, some small sheet metal tools, such as sheet metal shear, brake, roll, and hole punch, and a variety of hand tools. Also, the shop has CNC machining, MIG welding capabilities, and a waterjet (1 ft. × 1 ft. cutting area).

The SEAS Machine Shop Director Nick Bernardo has more than 25 years of diverse industrial and academic machining and fabrication experience. His expertise includes prototyping and CNC machining. He analyzes, advises, and assists students, staff, and faculty through individual and group instruction. He also provides constant safety oversight of all work in the shop.

The SEAS Machine Shop supports several Mechanical Engineering classes including: Mechanical Design (MENG 185), Machine Elements and Manufacturing Processes (MENG 325), Medical Device Design and Innovation (MENG 404), Mechanical Design: Process and Implementation I and II (MENG 487L and MENG 488L), Special Projects I (MENG 471 and MENG 472), and Special Projects II (MENG 473 and MENG 474).

Teaching Laboratory Facilities relevant to the Yale Mechanical Engineering Program:
CEID "Laboratory Spaces"

As described above, the CEID is composed of a number of stations that are used for hands-on activities associated with courses, undergraduate research and projects, and student organizations. The CEID is divided in four major spaces in addition to its instructional area: Studio (including the Electronics Stations), Machine and Metal Shop, Wood Shop, and Wet Lab. These spaces are described below.

The **CEID Studio** is a space with several stations equipped with 3D printers, hand tools, electronics fabrication and testing equipment, and a variety of materials and components available to members at no charge. In addition to this equipment, the two **CEID Electronics Stations** give students the capability to assemble prototype circuits on breadboards and PC boards, and to evaluate, test, and debug the circuits using a variety of diagnostic equipment. Equipment includes soldering units, circuit boards, Arduino hardware, and electronic components (resistors, capacitors, transistors, op amps, LEDs, servos, and sensors).
More detailed information about equipment in the Studio is presented in Appendix C.

The **CEID Machine and Metal Shop** and the **CEID Wood Shop** are accessible to students only with staff supervision. Students can use this space for projects, personal design pursuits, and classes. Available tools and equipment include a laser cutter, CNC milling machines, drill presses, an arbor press, belt sander, and a vertical band saw. Further details about tools and equipment are given in Appendix C.

The **CEID Wet Lab** has equipment that is designed to serve a variety of purposes. One purpose is to facilitate genetic engineering techniques using E. coli. Polymerase reactions may be run and the results may be analyzed using spectroscopic techniques and electrophoresis. Equipment includes but is not limited to: microscopes, transilluminator, vortex mixer, centrifuge, incubator, etc. A second purpose is to support work in microfluidics, including both the standard variety using PDMS (polydimethylsiloxane) molds as well as paper microfluidics more suited to diagnostics for the developing world. Equipment for this purpose includes, but is not limited to: vacuum pump and desiccator, microscopes, fiber optic illuminators, and a fume hood. A third purpose is to house instruments that are used to remove support material from parts produced by CEID 3D printers. More information about the CEID Wet Lab equipment appears in Appendix C.

Science education undergraduate teaching labs used by Yale School of Engineering students

In 2017 Yale opened state-of-the-art undergraduate teaching labs for five Yale science departments: Molecular Biophysics & Biochemistry; Molecular, Cellular, & Developmental Biology; Ecology & Evolutionary Biology; Chemistry; and Physics. Located in the Sterling Chemistry Lab, the science teaching lab renovations encompass 159,000 square feet, which include 31,600 square feet of additional space. The renovation project included the new teaching labs, an overhaul of mechanical systems, and new lounge areas and student lockers. These teaching labs are used by engineering students for lab courses in chemistry and physics. These improvements demonstrate Yale's continued investment in undergraduate educational facilities.

B. Computing Resources

SEAS and Yale College have a variety of computing resources throughout campus available for all students and faculty for academic purposes. The diverse range of classrooms facilitates a productive teaching education experience. From computers to whiteboards, projectors, and printers, to comfortable seating, appropriate lighting, and easy access, these facilities are ideal for the support of scholarly and professional activities for the Mechanical Engineering Program.

In the computer resource center in Dunham Laboratory Room 120, students have access to a variety of spaces with computing resources. This computer lab is available 7 days a week, 24 hours/day with key card access. There are 16 general access computers in this room. The room also has a printer station and an adjoining computer classroom (Room 120 D with 21 computers), which is accessible when not being used for instruction.

The networked computers in Dunham Laboratory Room 120 (as well as 17 Hillhouse and in the CEID) are all outfitted with the following software: ANSYS, SolidWorks, MATLAB, IBM SPSS Statistics Data Editor, Minitab 16 Statistical Software, SketchUp, State SE 13.0, Mathematica, DNR GPS, and Aspen HYSYS. In addition, LabVIEW, Origin, Microwave Office, COSMOL Multiphysics, and Ansoft HFSS & Maxwell 3D are available for course and research projects via the Yale Software Library and supported by Mikhael Guy from Yale's Science Research Software Core.

Among the six classrooms in 17 Hillhouse are three computer classrooms. These classrooms were designed to encourage discussion and interaction among students in smaller classes and lectures alike, mainly by replacing formerly stationary furniture with mobile tables and chairs. These rooms also include double-screen video projectors. All rooms are accessible 24/7 with a Yale ID card.

As previously mentioned, the Technology Enabled Active Learning (TEAL) Classroom 101 in 17 Hillhouse seats 126 students at small round tables with computers available at each table. Each table is connected to a video projector, allowing all groups to display their work to the entire class simultaneously on projection screens that line the walls. Equipment includes: annotation monitor (digital notes, annotation), Blu-ray player, document camera, DVD player, microphones (podium and lavaliere), plasma or LCD screens, projectors, and whiteboards.

Classroom 111 in 17 Hillhouse seats 52 students, with a computer station for each (PCs). There are 8 projectors (data and video capable), a DVD player, Blu-ray, a projector (HD 1920×1080), and whiteboards. This room is ideal for a classroom setting.

The Library Computer Classroom 07 in 17 Hillhouse is designed for lectures, presentations, and research. The classroom features 16 PC workstations with standard software. Outfitted with a podium and projectors, the classroom is an ideal space for holding lectures and presentations. Study tables with additional seating for 10 and whiteboards are available for individual or group study and research. The room also houses a printer/scanner/copier.

Arthur K. Watson Hall also contains a 38-station computer facility known as the Zoo, which is located on the third floor of the building. The facility is adjacent to a lounge and eating area, and is open 24/7. At the start of each semester, login accounts on the computers in the Zoo are set up for students taking computer science classes.

Beyond these engineering stations, Yale's Academic Computing Services supports hundreds of public computers that are located throughout campus and are intended for use by members of the Yale community. The computers have a common software image to provide ample access to academic software. Technical help with computing ranging from network connectivity to software installation can be obtained by contacting Yale Information Technology Services (ITS) Helpdesk via phone or email. Their automated ticket and scheduling system ensures that all issues are resolved promptly.

Undergraduates engaged in computational research in the Mechanical Engineering Program can also access Yale's significant high performance computing (HPC) facilities that are housed in the West Campus Data Center. Yale Faculty of Arts & Sciences (FAS) HPC operates two clusters. The Omega cluster includes over 8,500 Intel processors (cores), 12 GPU accelerators, and a 1.4-petabyte parallel file system, which makes it well suited to highly parallel work in a variety of fields including the physical sciences and engineering. The Grace cluster provides Yale with an additional 1,440 of the most modern Intel processors along with another petabyte of high-performance storage. Because the Grace cluster includes nodes with 20 cores and 128 gigabytes of memory each, it is especially appropriate for computations that require large amounts of memory and use multithreaded applications.

The University provides a user support staff through the Yale Center for Research Computing comprising six individuals with HPC and scientific computing expertise. The support staff, with an aggregate of over 125 person-years of HPC experience, assists users in developing applications and making effective use of the HPC clusters through its training and consultation activities. Potential undergraduate users can obtain login accounts through faculty research or course sponsors.

C. Guidance

Classroom & Computer Labs Guidance

The Mechanical Engineering Program Faculty, staff, and teaching assistants guide students regarding the safe use of laboratory equipment. The professors teaching Mechanical Design (MENG 185), Solid Mechanics and Materials Science Laboratory (MENG 286L), Machine Elements and Manufacturing Processes (MENG 325), and Fluid Mechanics and Thermodynamics Laboratory (MENG 363L), along with the associated Teaching Fellows (Ph.D. students serving as laboratory assistants, typically two per course), instruct students on the safe and proper use of equipment in each of these courses. The Program Faculty also instruct students on the availability and use of software needed throughout the curriculum. The Yale Science Research Software Core, HPC staff, and the ITS Helpdesk are also helpful resources for questions concerning software and hardware for computing.

SEAS Machine Shop, Design/Electrical Laboratory Guidance

Three full-time teaching support staff train and supervise students for all shop and laboratory activities, with an additional half-time employee providing support for chemical-based learning. Students are instructed in all safety guidelines prior to entering the laboratory, and appropriate signage is clearly posted. Students are guided and supervised as necessary for all laboratory activities to ensure learning and safe operating procedures.

Staff members are active participants who provide professional technical support for research and educational projects. They also serve as a resource for students in career counseling, advising, and networking. In addition to helping students, the staff also works closely with faculty on curriculum improvements, equipment assessment, and any other related topics to ensure the course objectives and student outcomes are being met.

CEID Guidance

To become a member of the CEID and use the tools and the shops it has to offer, students (and also staff and faculty) must participate in an initial orientation before they can use the space. This orientation covers emergency procedures and safety guidelines, such as personal protective equipment (eye wash, fire extinguisher use, safety glasses, etc.). In addition, there are formal trainings for the Machine and Metal Shop, Wood Shop, and 3D printers. Staff members (2 Ph.D.-level, 2 B.S.-level) are available full time from 9:00 am to 6:00 pm, and undergraduate staff is available from 6:00 pm to 9:00 pm. Access to the Machine and Metal Shop, Wood Shop, and Wet Lab is limited to staff only, and students are only allowed under their supervision and following extensive training.

D. Maintenance and Upgrading of Facilities

All computer resources are updated through Yale ITS, which monitors the computers remotely and upgrades them periodically.

For the facilities that are under the control of the Mechanical Engineering Program, the Program Faculty maintain and periodically upgrade laboratory equipment and computer resources. As needed, the SEAS teaching support staff can also assist with the equipment maintenance and preparation for use. Each year, the Yale Provost’s Office requests proposals for teaching lab equipment. The Mechanical Engineering Program received over $45K in new laboratory equipment from Provost Office funds over the past three years.

For the CEID, the equipment is checked and tested regularly by CEID staff to ensure safe and proper performance. In addition, annual service contracts are in place for high capital cost equipment. Tools are replaced on an as-needed basis as they wear out. Computing resources are monitored remotely, upgraded, and maintained by Yale ITS, and disk image software is upgraded annually. For the SEAS Machine and Metal Shop, all equipment is checked, tested, and maintained by the shop supervisor.

E. Library Services

The Yale University Library supports and enhances research, teaching, and learning. As part of this mission, the Library provides access to a collection of 15 million print and electronic items in formats including books, journals, and databases. The program is served by a professional librarian who is embedded in SEAS to respond to purchase requests, manage collections, teach information skills, and provide research services.

Service is the top priority, and the engineering librarian consults with faculty members to conduct course-related research education. During Academic Year 2019–2020, the engineering librarian conducted 24 orientation and instruction sessions with 380 participants. In addition, library professional staff offer support and training for citation management, geographic information systems, and statistics and data management.

SEAS students and faculty take advantage of a wide range of research resources and services provided by the 15 libraries and 600 staff comprising one of the largest library collections in the world. The engineering collections are located in the central campus library, which is Sterling Memorial Library. Science materials are also housed in the newly renovated Marx Science and Social Science Library, which includes collections in physics, biology, chemistry, and geology; the Mathematics Library; and the Medical Library. The Yale Library is a U.S. government and United Nations depository. Course reserves and e-reserves are provided and integrated with Yale’s course management system.

Access to collections is available during the academic term for as many as 17.5 hours per day at the Bass Library. Study space is provided 24 hours per day at the Marx Science and Social Science Library. A variety of learning/study spaces are available in campus libraries including individual carrels, tables, and group study rooms. Technology tools and services include workstations with internet access, productivity software, data manipulation software, mapping and GIS, presentation preparation, multimedia production, videoconferencing, printing, and scanning.

Students and faculty are provided many resources online via the Yale Library website for ease of access around the clock and around the world. The Library provides online access to thousands of databases for locating research articles, including Web of Science, Engineering Village/Compendex, Inspec, Chemical Abstracts/SciFinder Scholar, and the IEEE Electronic Library. The “Yale Links” resolver connects citations in these databases to full-text sources available to the Yale community. Researchers have access to more than 470,000 journals including major science and technology online periodical packages published by Elsevier Science Direct, Wiley, Springer, Oxford, IEEE, Association for Computing Machinery, American Chemical Society, American Physical Society, the American Society of Mechanical Engineers, as well as many other publishers and societies.

E-books are part of the collection and supplement the strong print collections in science and technology. Yale users have online access to important collections of engineering reference handbooks through AccessEngineering, Knovel, and CRC, including the CRC Handbook of Chemistry and Physics, Perry’s Chemical Engineers’ Handbook, and Marks’ Standard Handbook for Mechanical Engineers. Other online book subscriptions include major collections for engineering and chemical data, computing manuals, and academic texts.

Materials needed for research may be requested for purchase or through the Library's document delivery services. Articles and book chapters from items in the collection are available for scanning and electronic delivery in 1–2 business days. The Yale Library has partnered with major research libraries to offer the Borrow Direct system that allows books not available locally to be sent on loan within four business days. In addition, Yale provides interlibrary loan borrowing for books and online delivery of articles not available locally. Faculty and students can connect to library services remotely via a VPN client.

F. Overall Comments on Facilities

Program Faculty work with Yale's Office of Environmental Health & Safety (EHS) to ensure that all instructional equipment conforms to University safety standards. A representative from SEAS sits on Yale's Laboratory Safety Committee, and a staff member from EHS is specifically assigned to monitor safety and training in the SEAS laboratories and workshops. In addition, all undergraduates working in research at Yale during the summer must register through an online health and safety management system, EHS Integrator, which ensures that undergraduates received necessary training and faculty abide by the appropriate safety and mentoring standards. Also, one Mechanical Engineering Faculty member (Prof. Dollar) is the Chair of the university-wide Shop Safety Committee, and thus communicates frequently with Program faculty on the latest developments concerning shop and lab safety. Collectively the Faculty, teaching support staff, students, and EHS all work together to ensure the safety of Yale's facilities.

CRITERION 8. INSTITUTIONAL SUPPORT

A. Leadership

The Department of Mechanical Engineering & Materials Science (MEMS) is led by a Chair, who presides over all departmental matters, a Director of Undergraduate Studies (DUS), who presides over undergraduate affairs, and a Director of Graduate Studies (DGS), who covers all graduate student issues. Major decisions, such as faculty hiring recommendations and curricular changes, are made by the Program Faculty via majority vote. Minor decisions are often made directly by the Chair, DUS, or DGS. The DUS has the authority to determine course electives and satisfaction of prerequisites for students, but often consults with the Curriculum Committee (Chapter 2) before doing so.

The Chair is appointed by the Yale President, following consultation with departmental and possibly other faculty. The term of the appointment is three years. The Chair then appoints the DUS and the DGS, following consultation of the departmental faculty. The DUS and DGS appointments are reconfirmed annually.

Yale's School of Engineering & Applied Science (SEAS) is led by a Dean, who presides over the School. The SEAS Dean works directly with the Provost and Dean of the Faculty of Arts and Sciences (FAS) on administrative matters related to the School of Engineering & Applied Science. The Provost is Yale's chief educational and administrative officer after the President. The Office of the Provost oversees academic policies and activities university-wide. The FAS Dean's Office oversees faculty searches, recruitment, hiring, mentoring, promotions, retentions, and compensation for all ladder, instructional, and research faculty in the Faculty of Arts and Sciences, as well as departmental staffing, budgeting, strategic planning, and policies and practices throughout the FAS.

The SEAS Dean also partners with the Dean of Yale College (Yale's undergraduate program) and the Dean of the Graduate School of Arts and Sciences on teaching and research initiatives. The Department's DUS and DGS are the primary points of contact with Yale College and the Graduate School, with the SEAS Dean's Office providing oversight and School-wide coordination. The Yale Faculty Handbook (http://provost.yale.edu/faculty-handbook) details many of the issues related to faculty governance and operations.

B. Program Budget and Financial Support

Yale University provides a general appropriation fund for operations in the Department of Mechanical Engineering & Materials Science. Additional funds are made available from discretionary accounts within the Department. We believe that the financial resources are sufficient to accomplish the Program Educational Objectives and ensure continuity of the Mechanical Engineering Program.

In addition to these sources of funding, Program Chairs can request funds from the SEAS Dean to execute the Mechanical Engineering Program. If the fund request exceeds the amount in the Dean's budget, the Dean negotiates with the Provost's Office for additional funds. In particular, each year MEMS requests funds for non-ladder teaching positions to cover required and elective courses in the Program while faculty are on leave. In 2019–2020, the Provost's Office approved more than $285K to support non-ladder teaching faculty, including full-time Lecturers, Drs. Bennett and Booth, in the Mechanical Engineering Program. The Provost also controls a Science Development Fund, which has funds to address unusual opportunities for enhancing the quality of the engineering programs. These funds are provided if a compelling argument can be made regarding the benefit to Yale.

The Budget Office is responsible for the development of the Yale University annual operating budgets and long-range financial plans for presentation to and approval by University Officers and the Yale Corporation. The Office of the Provost establishes budget targets for individual units in the Faculty of Arts and Sciences. Unit budgets are established from historical information and projected programmatic needs of the units.

Recurring funding is provided centrally from general appropriations as well as unit-specific gift and endowed funds. Budgets are managed by Department Chairs and the SEAS Dean's Office. One-time funding requests for infrastructure improvements and investments in equipment are provided through several independent, merit-based processes, coordinated through the Office of the Provost and the Dean of the School.

Funding levels are sufficient to meet the programmatic needs of the Mechanical Engineering Program. Table 8-1 provides a four-year history of funding levels specific to support of the Mechanical Engineering teaching program.

Table 8-1. Mechanical Engineering Teaching Program Funding.

Mechanical Engineering & Materials Science	**FY17**	**FY18**	**FY19**	**FY20**
Faculty Salaries (burdened)	1,795,513	2,032,927	2,213,058	2,167,025
Allocated Support Staff Wages (burdened)	303,677	328,234	344,047	359,902
Direct Funded Operating	23,500	23,500	23,500	23,500
Allocated Support for Teaching Programs	30,574	29,130	34,345	41,729
Seminars	15,000	15,000	15,000	15,000
Discretionary	25,000	25,000	25,000	25,000
1x Teaching Equipment Funding	—	17,844	66,322	53,001
Teaching Assistants	656,550	673,650	689,850	706,950
Total	**2,849,814**	**3,145,286**	**3,411,122**	**3,392,107**

Support for Mechanical Engineering teaching is the responsibility of several units at Yale: the MEMS Department, SEAS, the Graduate School of Arts & Sciences, and the Provost's Office. Examples of teaching support include the funding of graders and teaching assistants, as well as the organization and running of teaching workshops, as detailed below.

Teaching experience is regarded as an integral part of the graduate training program at Yale, and all engineering graduate students are required to serve as a Teaching Fellow for one semester, typically during Year 2. Teaching duties normally involve assisting in laboratories or homework sessions and grading assignments for undergraduate courses; these duties are not expected to require more than 10 hours per week. In order to serve as a Teaching Fellow, graduate students either must be native speakers of English or must have met the oral English proficiency requirement. Graduate students in SEAS are not permitted to teach during their first year of study.

Generally undergraduate courses in engineering are supported with one Teaching Fellow (designated as a "TF10," meaning that the duties will not exceed 10 hours per week) for every 20 students in a lecture course or for every 10 students in a laboratory course. Lecture courses with an enrollment of fewer than 9 students are not awarded a Teaching Fellow. Funds for the Teaching Fellow program are provided by the Yale Graduate School. The assignment of TFs to Mechanical Engineering courses is initially based on the prior year's course enrollment, and then updated after the course shopping period has ended and the course enrollment is finalized. The course instructors work with the DUS and SEAS graduate registrar to identify suitable graduate student TFs for each Mechanical Engineering course. As mentioned above, all Ph.D. students are required to serve as a TF for one semester (TF10), but they are encouraged to be teaching fellows for additional semesters for an increased stipend.

Yale also supports undergraduate teaching via the Poorvu Center for Teaching and Learning. As part of the Office of the Provost, the Poorvu Center works with faculty to enable equitable and engaged teaching. The Center offers programs, funding, consultations, classroom observations, support, and digital resources designed for faculty and lecturers at Yale. One of their larger initiatives is the Faculty Teaching Academy, the goal of which is to engage new Yale faculty (within the first three years of being hired) in structured conversations in communities of practice with peers. Participants in the Faculty Teaching Academy (FTA) must complete six major components (the first of which is intensive training at a Summer Institute on Course Redesign and the last of which is submission of a final program portfolio) during a two-year period. Faculty receive a $3K contribution to their research accounts or professional development accounts upon completion of the program.

In addition, the Poorvu Center runs smaller initiatives for all Yale faculty such as Course (Re)Calibrate, Teaching and Learning Lunches, Diversity and Education events, and the Educational Technology Forum. Their workshops on using digital technology in the classroom (e.g., Poll Everywhere workshops) are popular with faculty seeking to engage students in the classroom via the use of electronic devices. There are also workshops for faculty who wish to learn more about the Canvas@Yale web portal (https://canvas.yale.edu/), Yale's Learning Management System, which includes an integrated set of web-based tools for teaching, learning, and sharing information such as a syllabus creation tool, tools for announcements, threaded discussions, and online file sharing. All students, faculty, and staff at Yale have access to the Canvas@Yale portal.

The Poorvu Center also provides funds to faculty for minor and major course enhancements (Instructional Enhancement Fund and the Rosenkranz Awards for Pedagogical Advancement), for which faculty must apply. The latter awards are relatively large (up to $10K) and the application process is quite competitive.

For Yale faculty as well as faculty at other universities, another Poorvu Center initiative is its set of regional Summer Institutes on Scientific Teaching funded by the Howard Hughes Medical Institute. The Summer Institutes are intensive multi-day workshops held throughout the United States that introduce STEM educators to the principles of evidence-based teaching.

For Yale graduate students, the Poorvu Center provides teaching consultations, classroom observations, and two series of workshops: Fundamentals of Teaching and Advanced Teaching. All first-time Teaching Fellows must complete, at a minimum, the 5-hour workshop entitled Teaching@Yale Day (T@YD), in which they learn about policies and guidelines, gain insight into student and faculty perspectives on graduate teaching, and are introduced to the many teaching resources available at the Poorvu Center. Professional development programming for graduate students is also available, as well as workshops on preparing for the academic job market.

Regarding the process for allotting resources to acquire, maintain, and upgrade infrastructure, the Department Chair has access to a large support network for the Mechanical Engineering Program. At one level, the School of Engineering & Applied Science can work with the Provost's Office to maintain and upgrade facilities and equipment. The Greenberg Engineering Teaching Concourse is one example of this process. In this case, the improvements were initiated by the School of Engineering & Applied Science with a request to the Provost. In such cases, once approved, SEAS works directly with Yale's campus planners and architects to upgrade infrastructure. A similar process is used for renovating classrooms and research labs.

On another level, the Department Chair has access to a support and maintenance network within the School of Engineering & Applied Science. Such support is coordinated through the Business Office for routine maintenance of infrastructure and for minor renovations. Such work may be accomplished using the School's staff or with assistance from Yale's Office of Facilities. For equipment maintenance, the Program is assisted by the SEAS Teaching Support Staff.

Regarding the adequacy of resources with respect to the Program and its students, resources have been sufficient to attain the Student Outcomes. For example, following the last General Review, when it was determined that the lab facilities were in need of revitalization, the School prioritized the need to create new lab space for all programs. As a part of that renewal, new lab equipment was also provided to outfit these spaces.

C. Staffing

Our world-renowned and diverse faculty members are leaders in their areas of research, and the

SEAS faculty-to-student ratio is one of the country's best, providing ample opportunity for students to gain individual access to their professors. Not only has SEAS succeeded in attracting top faculty, it seeks only the best in research, administrative, and technical staff — all dedicated to furthering the excellence of the School of Engineering & Applied Science. The Department and School are assisted in these efforts by a fully engaged Yale Office of Human Resources. The University's compensation, benefits, training and development programs help make Yale a desirable and preferred employer.

The SEAS support staff includes teaching lab specialists, financial managers, a Director of Communications, Dean, Deputy Dean, Assistant Dean, Dean's support team, and several administrative assistants. In addition to Department Faculty (and teaching assistants), the following individuals within SEAS and CEID provide direct support to the Program. The support staff for the Department includes:

(a) Technical support:
- Teaching lab support specialists (Glenn Weston-Murphy, Kevin Ryan, Nick Bernardo)
- Computer support specialists (Information Technology Services)
- Student computing assistants (Information Technology Services)

(b) Administrative personnel who conduct the business activities supporting our Programs:
- Dean of School of Engineering & Applied Science (Jeffrey Brock)
- Deputy Dean of School of Engineering & Applied Science (Vincent Wilczynski)
- Assistant Dean for Science and Engineering (Sarah Miller)
- Director of Communications (Steven Geringer)
- Director of News and Outreach (William Weir)
- Lead Administrator (Denny Kalenzaga)
- Facilities Operations (Andy Morcus)

(c) Department of Mechanical Engineering & Materials Science Administrative Support (Mary MacNicholl [Administrative Associate to Program Chair], Leslie Radcliffe, Janet O'Dell)

(d) CEID staff:
- Director (Vincent Wilczynski)
- Assistant Director (Dr. Joseph Zinter)
- Senior Research Scientist (Dr. Lawrence Wilen)
- Design Fellows (2019–2020 Fellows: Antonio Medina, Ashlyn Oakes)
- Undergraduate Aides

D. Faculty Hiring and Retention

New faculty members are hired based on national searches for junior and senior positions. When a person is recommended for a ladder faculty position through the search and voting processes of a department in the Faculty of Arts and Sciences, the recommendation is reviewed by the Dean of Yale College, the Dean of the Graduate School, the Dean of the School of Engineering & Applied Science, or by an appointments committee. Appointments to the rank of assistant professor are reviewed by the Dean of the School of Engineering & Applied Science.

Appointments to the ranks of associate professor on term or with tenure and to full professor are reviewed by the Tenure Appointments and Promotions Committee for the Physical Sciences Division. The policies and procedures for hiring are detailed in the Faculty Handbook that is promulgated by the Provost's Office.

Each new faculty member is provided with a start-up package from the Office of the Provost sufficient to allow them to establish their laboratory and research program. Faculty members are also provided with cost-matching support that can be used to purchase additional major equipment through such programs as the NSF Major Research Instrumentation Program and Defense University Research Instrumentation Program. Funds for travel assistance to national and international scientific meetings for the faculty can also be obtained through the Office of the Provost.

Yale University is very committed to retaining Faculty, and especially so regarding tenured Faculty. In addition to the generous leave policies, Yale has a faculty support and reward system that recognizes success, supports expanding research programs, and strives to meet Faculty professional development and personal growth needs.

E. Support of Faculty Professional Development

The Office of the Provost provides funds for faculty to travel to professional and scientific meetings. For tenured faculty, the maximum amount of reimbursement is $600 per academic year; for non-tenured faculty, the maximum is $1,200 each academic year, and in certain cases persons holding full-time Adjunct appointments are also eligible. To qualify for a travel grant, the faculty member must actively participate in the meeting by delivering a presentation, chairing a panel, serving as an officer of a professional association, contributing as a stated participant in a formal discussion, or participating in a significant way. Speaking as a lecturer or visitor at another university does not qualify for use of these funds, unless the event is a meeting that includes faculty from other universities.

Beginning faculty members are typically provided either a complete or partial release from teaching duties during their first semester at Yale to allow them to develop their research program. The typical teaching load after that period is one course per semester.

Ample sabbatical leaves are provided. Tenured professors are eligible for triennial, one-semester leaves at full salary. As established in Yale's Tenure and Appointments Policy, assistant professors are eligible for a one-year paid leave during Years 2–4 of their initial appointment, and associate professors are eligible for a one-year paid leave in Years 1–2 following their promotion.

PROGRAM CRITERIA

The ABET Program Criteria for Mechanical Engineering include two elements, Curriculum and Faculty, and are reproduced below.

Program Criteria for Mechanical and Similarly Named Engineering Programs

These program criteria will apply to all engineering programs including "mechanical" or similar modifiers in their titles.

1. Curriculum

   The curriculum must require students to apply principles of engineering, basic science, and mathematics (including multivariate calculus and differential equations); to model, analyze, design, and realize physical systems, components, or processes; and prepare students to work professionally in either thermal or mechanical systems while requiring topics in each area.

2. Faculty

   The program must demonstrate that faculty members responsible for the upper-level professional program are maintaining currency in their specialty area.

The two Program Criteria for Mechanical Engineering are consistent with our Program Educational Objectives described in Chapter 2. The Curriculum for the Mechanical Engineering Program was described previously in Chapter 1 and appears online at http://catalog.yale.edu/ycps/subjects-of-instruction/mechanical-engineering/.

In this chapter, details are provided to document that the ME Program curriculum satisfies the ABET Program Criterion for the Mechanical Engineering curriculum. The criteria are supported by specific courses in the curriculum as detailed in the following list. The course artifacts (e.g., the syllabi and supporting material available during the visit) substantiate the attainment of the curriculum aspects of the Program Criteria.

Knowledge of Engineering is addressed in the following courses:

- EENG 200: Introduction to Electronics
- MENG 211: Thermodynamics for Mechanical Engineers
- MENG 280: Mechanical Engineering I: Strength and Deformation of Mechanical Elements
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 361: Mechanical Engineering II: Fluid Mechanics
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science
- MENG 390: Mechatronics Laboratory
- MENG 365: Chemical Propulsion Systems [elective]

- MENG 400: Computer-Aided Engineering [elective]
- MENG 469: Aerodynamics [elective]
- ENAS 118: Introduction to Engineering, Innovation, and Design [elective]
- BENG 411: BioMEMS and Biomedical Microdevices [elective]

Knowledge of Basic Science is addressed in the following courses:

Chemistry:

- CHEM 163: Comprehensive University Chemistry I

  Any chemistry lecture course numbered 161 or higher is acceptable. Mechanical Engineering students usually take CHEM 163, which is the first semester of the introductory sequence aimed at students with some secondary school exposure to chemistry. A grade of 4 or 5 on the Chemistry Advanced Placement (AP) exam, a 7 on the International Baccalaureate (IB) Chemistry exam, or successful completion of a similar course at another university that is approved by the Chemistry DUS is also sufficient to meet this requirement. In these cases, fulfillment of the Chemistry requirement is noted on the transcript or tracked by the Mechanical Engineering DUS via official copies of the AP or IB test scores.

Calculus-Based Physics:

- PHYS 180: University Physics I
- PHYS 181: University Physics II

  Students may instead choose to take a more advanced course sequence, such as PHYS 200 and 201 or PHYS 260 and 261, to fulfill this requirement.

- PHYS 165L: General Physics Laboratory I
- PHYS 166L: General Physics Laboratory II

  Students may instead choose to take the more advanced laboratory course sequence, PHYS 205L and 206L, to fulfill this requirement.

- G&G 322: Physics of Weather and Climate [elective]
- G&G 342: Introduction to Earth and Environmental Physics [elective]

Knowledge of Mathematics (including multivariable calculus and differential equations) is addressed in the following courses:

Mathematics

- MATH 112: Calculus of Functions of One Variable I
- MATH 115: Calculus of Functions of One Variable II
- ENAS 151: Multivariable Calculus for Engineers
  (or MATH 120: Calculus of Functions of Several Variables)
- MATH 222: Linear Algebra with Applications
  (or MATH 225: Linear Algebra and Matrix Theory)
- ENAS 194: Ordinary and Partial Differential Equations with Applications
  (or MATH 246: Ordinary Differential Equations)

- PHYS 301: Introduction to Mathematical Methods of Physics [elective]
- S&DS 220: Introductory Statistics, Intensive [elective]
- S&DS 230: Data Exploration and Analysis [elective]

Computing and Numerical Methods:

- ENAS 130: Introduction to Computing for Engineers and Scientists
- MENG 441: Applied Numerical Methods for Differential Equations [elective]
- CPSC 201: Introduction to Computer Science [elective]
- CPSC 223: Data Structures and Programming Techniques [elective]
- CPSC 472: Intelligent Robotics [elective]

Knowledge of Thermal Systems is addressed in the following courses:

- MENG 211: Thermodynamics for Mechanical Engineers
- MENG 285: Introduction to Materials Science
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science
- MENG 365: Chemical Propulsion Systems [elective]
- MENG 464: Forces on the Nanoscale [elective]
- MENG 469: Aerodynamics [elective]
- BENG 350: Physiological Systems [elective]
- BENG 351: Biotransport and Kinetics [elective]
- BENG 434: Biomaterials [elective]
- CENG 300: Chemical Engineering Thermodynamics [elective]
- EENG 406: Photovoltaic Energy [elective]
- G&G 322: Physics of Weather and Climate [elective]
- G&G 342: Introduction to Earth and Environmental Physics [elective]

Knowledge of Mechanical Systems is addressed in the following courses:

- MENG 280: Mechanical Engineering I: Strength and Deformation of Mechanical Elements
- MENG 285: Introduction to Materials Science
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 361: Mechanical Engineering II: Fluid Mechanics
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science
- MENG 390: Mechatronics Laboratory
- MENG 365: Chemical Propulsion Systems [elective]
- MENG 459: Neuromuscular Biomechanics [elective]
- MENG 464: Forces on the Nanoscale [elective]
- MENG 469: Aerodynamics [elective]
- BENG 350: Physiological Systems [elective]
- BENG 353: Introduction to Biomechanics [elective]

- BENG 411: BioMEMS and Biomedical Microdevices [elective]
- BENG 434: Biomaterials [elective]

Ability to Model, Analyze, Design, and Realize Physical Systems, Components, or Processes is addressed in the following courses:

- EENG 200: Introduction to Electronics
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II
- MENG 185: Mechanical Design [elective for the Class of 2020 and earlier; required for the Class of 2021 and beyond]
- MENG 325: Machine Elements and Manufacturing Processes [elective for the Class of 2020 and earlier; required for the Class of 2021 and beyond]
- MENG 400: Computer-Aided Engineering [elective]
- MENG 404: Medical Device Design and Innovation [elective]
- MENG 469: Aerodynamics [elective]
- MENG 471: Special Projects I (fall) [elective]
- MENG 472: Special Projects I (spring) [elective]
- MENG 473: Special Projects II (fall) [elective]
- MENG 474: Special Projects II (spring) [elective]
- ENAS 118: Introduction to Engineering, Innovation, and Design [elective]
- ENAS 400: Making It: Product Design and Entrepreneurship [elective]
- ENAS 778: Advanced Robotic Systems [elective]
- BENG 351: Biotransport and Kinetics [elective]
- BENG 405: Biotechnology and the Developing World [elective]
- BENG 411: BioMEMS and Biomedical Microdevices [elective]
- BENG 434: Biomaterials [elective]
- CPSC 472: Intelligent Robotics [elective]
- EENG 406: Photovoltaic Energy [elective]

Several of these courses (EENG 200, MENG 286L, MENG 363L, MENG 390, MENG 487L, MENG 488L, MENG 185, MENG 325, MENG 404, MENG 471, MENG 472, MENG 473, MENG 474, and ENAS 400) have already been described in detail in the “Major Design Experience that Prepares Students for Engineering Practice” section of Chapter 5. One detail not mentioned in that section was the titles of the design projects completed by Mechanical Engineering B.S. students in two of the upper-level project-based courses in Academic Year 2019–2020.

The four team-based design projects in MENG 487L/488L (Mechanical Design: Process and Implementation I and II) for Academic Year 2019–2020 were as follows:

- Dirty Laundry: A Combination Washer/Dryer Using Novel Drying Techniques
  Team: Pamela Banner, Victoria Palmer, Mitchell Smith, and Zach Wright
  Technical Adviser: Walter Bircher, Teaching Fellow

- Longbow: A Soft Exo-Suit for Warehouse Workers
  Team: Calvin Chen, Duncan Lee, Tallak Melland, and Sinem Sinmaz
  Technical Adviser: Walter Bircher, Teaching Fellow

- plA+ne: A Hybrid-Electric Drone Aircraft for Surveillance and Reconnaissance
  Team: Erin Dowling, Alex Hoganson, Jonathan Li, Ethan O'Reilly, and Brian Rhee
  Technical Adviser: Dr. Joran Booth, Lecturer

- Triple Threat: A Three-Tier Pool Security System for Preventing the Injury and Death of a Small Child
  Team: Mohamed Anwar Akkari, Malcolm Dixon, Rebekah Nemeth, and Evan Smith
  Technical Adviser: Dr. Joran Booth, Lecturer.

The four design projects completed by B.S. Mechanical Engineering students in Special Projects I (MENG 471) in Fall 2019 were as follows:

- Mapping the High-Entropy Alloy Space in High-Throughput
  Student: Pamela Banner
  Adviser: Prof. Jan Schroers, Mechanical Engineering & Materials Science

- Solid Rocket Motor Design: Theory and Formulation of an APCP Propellant with Simulated Motor Design (two-semester project)
  Student: Alexander C.C. Hoganson
  Adviser: Prof. Alessandro Gomez, Mechanical Engineering & Materials Science

- Optimizing Rate-Activated Tethers
  Students: Aidan Hynes and Laura Wayland
  Adviser: Prof. Eric Brown, Mechanical Engineering & Materials Science

- Addressing Tibial Bone Loss in Revision Total Knee Arthroplasty Surgery
  Student: Nguyen Pham
  Advisers: Dr. Daniel Wiznia and Dr. Steven Tommasini, Yale School of Medicine.

More information about the MENG 471 projects listed above can be found at https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-471473-projects-2019.

The three design projects completed by B.S. Mechanical Engineering students in Special Projects I (MENG 472) and Special Projects II (MENG 474) in Spring 2020 were as follows:

- A Modular Water-Resistant Chassis for a Turtle-Inspired Amphibious Robot
  Student: Andonny Garcia
  Adviser: Prof. Rebecca Kramer-Bottiglio, Mechanical Engineering & Materials Science

- Solid Rocket Motor Design: Theory and Formulation of an APCP Propellant with Simulated Motor Design (two-semester project)
  Student: Alexander C.C. Hoganson
  Adviser: Prof. Alessandro Gomez, Mechanical Engineering & Materials Science

- Orthopedic Implants as Prophylactic Intervention at the Hip
  Student: Brian Rhee
  Advisers: Dr. Daniel Wiznia and Dr. Steven Tommasini, Yale School of Medicine.

More information about the MENG 472 and MENG 474 projects listed above can be found at https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-472474-projects-2020.

Among the courses in which students develop their ability to model, analyze, design, and realize physical systems, components, or processes, the courses that were not previously described in the "Major Design Experience that Prepares Students for Engineering Practice" section of Chapter 5 are now touched upon. Each brief description below focuses on aspects of modeling, analysis, and design.

- Computer-Aided Engineering (MENG 400): Throughout the semester, students learn to use computer-aided design (CAD) software packages, including 3D drafting/assembly modeling, motion modeling, finite element analysis (FEA), and flow analysis. They also use computer-aided manufacturing (CAM) hardware and software. An end-of-semester project enables students to bring together CAD/CAM skills learned in the course.
- Aerodynamics (MENG 469): Students complete open-ended design exercises (e.g., design of airfoils) using Mathematica and Javafoil. They do so immediately after their first exposure to airfoil shapes, and they also do so later in the semester, after learning about viscous effects, drag, and boundary layer separation. These exercises give students a better feel for how the theoretical concepts they learn in class influence actual airfoil design.
- Introduction to Engineering, Innovation, and Design (ENAS 118): After spending several weeks gaining hands-on experience in a survey of engineering disciplines and computer science, students apply skills in computer modeling and fabrication in a team-based final project for a real client. Each team designs and constructs a working prototype of an original device or system that addresses the client's needs.
- Advanced Robotic Systems (ENAS 778): After learning concepts associated with advanced robotic design through a series of mini-projects, students then work in small groups of two or three to conceive of, design, analyze, and demonstrate a novel robotic hardware concept. A number of progress updates are required, including a CAD model, a prototype, and the final design itself.
- Biotransport and Kinetics (BENG 351): Students apply fundamental principles learned in class to problems such as the analysis of cellular signaling networks, rational drug design, and the development of strategies for drug delivery. They also complete a design project to apply these principles to analyze a biomolecular network that implements a biosensor using MATLAB, optimizing it for a specific design objective.
- Biotechnology and the Developing World (BENG 405): After spending much of the semester developing the necessary biotechnology-related skills, students work in teams to prepare a proposal based on the Gates Foundation Grand Challenge Exploration to address the initiative's call. The proposal includes designing a strategy that incorporates biotechnology, providing an expense report, and developing an implementation timeline.

- BioMEMS and Biomedical Microdevices (BENG 411): Student teams complete a design project on any topic in micro- or nanobiotechnology (e.g., in vitro diagnostics, in vivo imaging, drug delivery, implantable microchips, surgical microdevices, etc.). They submit a report that includes background, significance, design rationale, fabrication (synthesis) procedure, in vitro and in vivo tests, clinical tests, and/or preparation for FDA evaluation.
- Biomaterials (BENG 434): As part of their homework at various points in the semester, students complete several design exercises in which they apply skills and concepts learned in class. In particular, students design a hip implant prosthesis, a coronary artery, and replacement body tissues, as well as a drug delivery system.
- Intelligent Robotics (CPSC 472): After learning concepts related to intelligent autonomous systems and how to apply mathematics to understand dynamical systems, students work as part of a team to analyze, design, and build a robotic system. The robotic system must have complex functions and abilities, such as the abilities to learn, perceive, and adapt.
- Photovoltaic Energy (EENG 406): After students learn the semiconductor background necessary for analyzing solar cells in detail, as well as how to connect material properties to aspects of solar cell design, processing, and performance, they apply this knowledge to a design project. Their project must explore applications of photovoltaic technology, as well as its limitations.

The second of the two Program Criteria requires that faculty maintain currency in their areas of specialty. As shown in Appendix B, the MEMS Faculty members maintain currency in their specialties by participating in professional society meetings as organizers of sessions and giving keynote and invited presentations. Each member of the Department has an excellent record of research and publication in archival journals. To ensure an up-to-date database, every Yale faculty member is required to submit a Faculty Activity Report in which they list their research, teaching, and professional activities for the previous year. This information is then used by the Department Chair, the Dean of the School of Engineering & Applied Science, and the Provost's Office in determining various awards and compensation raises.

Appendix A – Course Syllabi

Required Courses:

- ENAS 130: Introduction to Computing for Engineers and Scientists
- ENAS 194: Ordinary and Partial Differential Equations with Applications
- EENG 200: Introduction to Electronics
- MATH 222: Linear Algebra with Applications
- MENG 211: Thermodynamics for Mechanical Engineers
- MENG 280: Mechanical Engineering I: Strength and Deformation of Mechanical Elements
- MENG 285: Introduction to Materials Science
- MENG 286L: Solid Mechanics and Materials Science Laboratory
- MENG 361: Mechanical Engineering II: Fluid Mechanics
- MENG 363L: Fluid Mechanics and Thermodynamics Laboratory
- MENG 383: Mechanical Engineering III: Dynamics
- MENG 389: Mechanical Engineering IV: Fluid and Thermal Energy Science
- MENG 390: Mechatronics Laboratory
- MENG 487L: Mechanical Design: Process and Implementation I
- MENG 488L: Mechanical Design: Process and Implementation II

Electives:

- MENG 185: Mechanical Design
- MENG 325: Machine Elements and Manufacturing Processes
- MENG 365: Chemical Propulsion Systems
- MENG 400: Computer-Aided Engineering
- MENG 404: Medical Device Design and Innovation
- MENG 441: Applied Numerical Methods for Differential Equations
- MENG 459: Neuromuscular Biomechanics
- MENG 464: Forces on the Nanoscale
- MENG 469: Aerodynamics
- MENG 471: Special Projects I (fall)
- MENG 472: Special Projects I (spring)
- MENG 473: Special Projects II (fall)
- MENG 474: Special Projects II (spring)
- ENAS 118: Introduction to Engineering, Innovation, and Design
- ENAS 400: Making It: Product Design and Entrepreneurship
- ENAS 778: Advanced Robotic Systems
- BENG 350: Physiological Systems
- BENG 351: Biotransport and Kinetics
- BENG 353: Introduction to Biomechanics
- BENG 405: Biotechnology and the Developing World

- BENG 411: BioMEMS and Biomedical Microdevices
- BENG 434: Biomaterials
- CENG 300: Chemical Engineering Thermodynamics
- CPSC 201: Introduction to Computer Science
- CPSC 223: Data Structures and Programming Techniques
- CPSC 472: Intelligent Robotics
- EENG 406: Photovoltaic Energy
- G&G 322: Physics of Weather and Climate
- G&G 342: Introduction to Earth and Environmental Physics
- PHYS 301: Introduction to Mathematical Methods of Physics
- S&DS 220: Introductory Statistics, Intensive
- S&DS 230: Data Exploration and Analysis

Prerequisites:

- CHEM 163: Comprehensive University Chemistry I
- MATH 112: Calculus of Functions of One Variable I
- MATH 115: Calculus of Functions of One Variable II
- MATH 120*: Calculus of Functions of Several Variables*
- ENAS 151: Multivariable Calculus for Engineers
- PHYS 180: University Physics I
- PHYS 181: University Physics II
- PHYS 165L: General Physics Laboratory I
- PHYS 166L: General Physics Laboratory II

*MATH 120 can be taken in place of ENAS 151.

1. Course number and name: ENAS 130
Introduction to Computing for Engineers and Scientists

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Beth Anne V. Bennett

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Lecture slides and sample codes.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      An introduction to the use of the C and C++ programming languages and the software packages Mathematica and MATLAB to solve a variety of problems encountered in mathematics, the natural sciences, and engineering. General problem-solving techniques, object-oriented programming, elementary numerical methods, data analysis, and graphical display of computational results.

   b. Prerequisites or co-requisites for the course: MATH 115 or equivalent. Recommended preparation: previous programming experience.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop ability to write programs in C and C++ in order to solve mathematical and engineering problems using simple numerical methods, to analyze data, and to visualize data graphically.
      - Develop ability to write programs using a sophisticated software package (MATLAB) in order to solve mathematical and engineering problems using simple numerical methods and using built-in functions for data analysis and graphics.
      - Develop ability to debug computer codes and create properly functioning codes.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Introduction to programming; problem solving using C (data types, I/O, conditionals, operator precedence, loops, functions, scope of a variable, pointers, graphics, arrays, dynamic memory allocation, structures, debugging, recursion); problem solving using MATLAB (arithmetic, variables, matrix operations, scripts, plotting, I/O, debugging, conditionals, loops, functions); problem solving using C++ (function overloading, classes, I/O, more about dynamic array allocation, graphics); applications throughout the course

1. Course number and name: ENAS 194/APHY 194
Ordinary and Partial Differential Equations with Applications

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Mitchell Smooke

4. Textbooks (title, author, publisher, year): Elementary Differential Equations and Boundary Value Problems, 10th edition, by William E. Boyce and Richard C. DiPrima, John Wiley & Sons, Inc., 2012.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Basic theory of ordinary and partial differential equations useful in applications. First- and second-order equations, separation of variables, power series solutions, Fourier series, Laplace transforms.

   b. Prerequisites or co-requisites for the course: ENAS 151 or equivalent, and knowledge of matrix-based operations.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Attain detailed knowledge of analytical techniques for solving differential equations.
      - Develop ability to apply analytical techniques to solve both ordinary differential equations (ODEs) and partial differential equations (PDEs).

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Characterizing differential equations; first-order ODEs; second-order linear ODEs with constant coefficients; mechanical and electrical vibrations; higher-order linear ODEs with constant coefficients; series solutions of second-order linear ODEs with non-constant coefficients; Laplace transforms; systems of first-order linear ODEs; Fourier series; solution of linear PDEs (heat equation, wave equation, and Laplace equation) by separation of variables

1. Course number and name: EENG 200
   Introduction to Electronics

2. Credits and contact hours: 1.0 credits, 1.7 hours/week + 6 lab sessions throughout the term

3. Instructor's name: Mark Reed

4. Textbooks (title, author, publisher, year): Electrical Engineering: An Introduction, 2nd edition, by Steven E. Schwarz and William G. Oldham, Oxford University Press, 1993.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Introduction to the basic principles of analog and digital electronics. Analysis, design, and synthesis of electronic circuits and systems. Topics include current and voltage laws that govern electronic circuit behavior, node and loop methods for solving circuit problems, DC and AC circuit elements, AC power, frequency response, nonlinear circuits, semiconductor devices, and small-signal amplifiers. A lab session approximately every other week.

   b. Prerequisites or co-requisites for the course: After or concurrently with MATH 115 or equivalent.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand basic electric circuits, including both passive and active varieties, as building blocks of analog systems.
      - Understand the basic concepts of some elementary semiconductor devices for analog and digital applications.
      - Analyze and design moderately sophisticated electronic circuits.
      - Be able to take more advanced electronic circuits-related courses.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: DC circuit elements; Kirchoff's Laws; node and loop methods; current and voltage dividers; Thevenin and Norton Equivalent Circuits; maximum power transfer; ideal operational amplifier; capacitors and inductors; sinusoids and complex numbers; phasors, power in sinusoidal signals; impedance and resonance; frequency response, filters, and Bode plots; transient response; impedance matching and transformers; AC power, 3 phase; nonlinear circuits, semiconductors, and diodes; bipolar junction transistors, BJT amplifiers, small signal biasing, BJT small signal analysis, and model; MOSFETs, small signal MOSFETs; intro digital logic; CMOS logic; flip flops; optoelectronics

1. Course number and name: MATH 222
   Linear Algebra with Applications

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Tom VandenBoom

4. Textbooks (title, author, publisher, year): Linear Algebra and Its Applications, 4th edition, by Gilbert Strang, Cengage Learning, 2006.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Matrix representation of linear equations. Gauss elimination. Vector spaces. Linear independence, basis, and dimension. Orthogonality, projection, least squares approximation; orthogonalization and orthogonal bases. Extension to function spaces. Determinants. Eigenvalues and eigenvectors. Diagonalization. Difference equations and matrix differential equations. Symmetric and Hermitian matrices. Orthogonal and unitary transformations; similarity transformations.

   b. Prerequisites or co-requisites for the course: After MATH 115 or equivalent. May not be taken after MATH 225.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to represent linear equations in matrix form and solve them.
      - Understand vector spaces and related concepts.
      - Be able to calculate and manipulate determinants, eigenvalues, and eigenvectors of a matrix.
      - Understand importance of and be able to perform matrix transformations.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Matrix representation of linear equations; Gauss elimination; inverses, transposes, and permutations; vector spaces; linear independence, basis, and dimension; orthogonality, projection, least squares approximation, Gram-Schmidt; determinants; eigenvalues and eigenvectors; diagonalization; similar matrices; singular value decomposition

1. Course number and name: MENG 211
   Thermodynamics for Mechanical Engineers

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Diana Qiu

4. Textbooks (title, author, publisher, year): Fundamentals of Engineering Thermodynamics, 8th edition, by M. J. Moran, H. N. Shapiro, D. D. Boettner, and M. B. Bailey, John Wiley and Sons, 2014.
   a. Supplemental materials: Understanding Thermodynamics, H. C. Van Ness, Dover, 1983; Thermodynamics, E. Fermi, Dover, 2012.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Study of energy and its transformation and utilization. First and Second Laws for closed and open systems, equations of state, multicomponent nonreacting systems, auxiliary functions (H, A, G), and the chemical potential and conditions of equilibrium. Engineering devices such as power and refrigeration systems and their efficiencies.

   b. Prerequisites or co-requisites for the course: PHYS 180 or 200, and MATH 115.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to state the first law of thermodynamics and define basic concepts like heat, work, and the difference between various forms of energy.
      - Be able to judge the thermodynamic properties of pure substances.
      - Be able to describe energy exchange processes.
      - Understand entropy and its applications.
      - Understand thermodynamic cycles, availability, and reversibility.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: First Law of Thermodynamics; thermodynamic properties of pure substances; mass and energy balances; Second Law of Thermodynamics; entropy; power; systems; thermodynamic relations

1. Course number and name: MENG 280
   Mechanical Engineering I: Strength and Deformation of Mechanical Elements

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Eric Brown

4. Textbooks (title, author, publisher, year): Statics and Mechanics of Materials, 4th edition, by Russell C. Hibbeler, Pearson, 2014.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Elements of statics; mechanical behavior of materials; equilibrium equations, strains and displacements, and stress-strain relations. Elementary applications to trusses, bending of beams, pressure vessels, and torsion of bars.

   b. Prerequisites or co-requisites for the course: PHYS 180 or 200, and MATH 115.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to analyze a rigid structure to determine if it is in mechanical equilibrium, and determine forces and torques on different components, including complex networks (trusses) with many parts.
      - Be able to calculate stress and strain in materials based on applied forces and torques.
      - Be able to describe and analyze deformation and failure of materials in terms of stress and strain.
      - Be able to analyze materials subject to different types of loads, such as tension/compression of columns, bending of beams, torsion of shafts, and shear, and materials subject to combinations of these loads (e.g., pressure vessels).
      - Be able to design optimal part sizes to avoid any type of failure while minimizing weight or cost.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Rigid body equilibrium, trusses, external/internal forces, stress, strain, principal stress, stiffness, toughness, strength, plasticity, deformation under axial loads, thermal stress, internal moments, deflection of beams under various loads, bending energy, buckling, material failure

1. Course number and name: MENG 285
Introduction to Materials Science

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Sudhangshu Bose

4. Textbooks (title, author, publisher, year): Materials Science and Engineering: An Introduction, 8th edition, by William D. Callister, Jr., and David G. Rethwisch, John Wiley & Sons, 2010 (same text as for MENG 286L).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Study of the atomic and microscopic origin of the properties of engineering materials: metals, glasses, polymers, ceramics, and composites. Phase diagrams; diffusion; rates of reaction; mechanisms of deformation, fracture, and strengthening; thermal and electrical conduction.

   b. Prerequisites or co-requisites for the course: Elementary calculus and background in basic mechanics (deformation, Hooke's law) and structure of atoms (orbitals, periodic table).

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Provide an introduction to the principles, design, and application of a wide range of engineering materials (metals, semiconductors, polymers, ceramics, and composites).
      - Develop an understanding of the relationships among processing, microstructure, and properties in materials science.
      - Prepare students to be able to evaluate and compare structural theories with experimental results obtained in the laboratory when they take MENG 286L.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Atomic and microscopic origin of the properties of engineering materials such as metals, ceramics, glasses, polymers, semiconductors, and composites; phase diagrams, diffusion, heat treatment, and rates of reaction; mechanisms of deformation and fracture under steady state, cyclic, and thermal loads, and their implications in practical applications; mechanisms to strengthening materials; design and application of materials; processing of classical (glass, steel) as well as modern (optical fibers, nano materials) materials; basics of materials and component failure in real applications and associated mechanisms.

1. Course number and name: MENG 286L
   Solid Mechanics and Materials Science Laboratory

2. Credits and contact hours: 0.5 credits, 2.5 hours/week

3. Instructor's name: Jan Schroers

4. Textbooks (title, author, publisher, year): Materials Science and Engineering: An Introduction, 8th edition, by William D. Callister, Jr., and David G. Rethwisch, John Wiley & Sons, 2010 (same text as for MENG 285).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Experiments that involve either structural mechanics or materials science. Comparisons between structural theories and experimental results. Relationships among processing, microstructure, and properties in materials science. Introduction to techniques for the examination of the structure of materials.

   b. Prerequisites or co-requisites for the course: None.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Working in pairs (or, for certain labs, working with one-third of the class), be able to carry out labs that focus on the materials aspect of mechanical engineering.
      - Be able to identify a significant story from the first four labs.
      - With a partner, demonstrate technical communication skills by writing up the four-lab sequence and by giving a 15-minute presentation on one lab.
      - Demonstrate acquisition of the following technical skills:
        - Be able to work in groups (one-third of the class and with a partner).
        - Develop the ability to characterize materials via various techniques.
        - Be able to analyze error.
        - Manage the writing of a scientific document.
        - Identify the significance of the various labs in a four-lab report and a presentation.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. Brief list of topics to be covered: Lab safety; fabrication of alloys; mechanical characterization; mechanical deformation; material groups; material selection; error analysis; factor of safety in design; project management; scientific documents; patents

1. Course number and name: MENG 361
Mechanical Engineering II: Fluid Mechanics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Alessandro Gomez

4. Textbooks (title, author, publisher, year): F*ox and McDonald's Introduction to Fluid* Mechanics, 9th edition, by Philip J. Pritchard and John W. Mitchell, John Wiley & Sons, 2015.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Mechanical properties of fluids, kinematics, Navier-Stokes equations, boundary conditions, hydrostatics, Euler's equations, Bernoulli's equation and applications, momentum theorems and control volume analysis, dimensional analysis and similitude, pipe flow, turbulence, concepts from boundary layer theory, elements of potential flow.

   b. Prerequisites or co-requisites for the course: ENAS 194 or equivalent, and physics at least at the level of PHYS 180.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to solve hydrostatics problems to compute pressures and forces.
      - Be able to calculate kinematic properties of flow fields and predict behavior.
      - Be able to apply control-volume analysis to compute average flow properties.
      - Be able to solve the Navier-Stokes equations in simple geometries.
      - Be able to nondimensionalize equations of motion and interpret nondimensional groups.
      - Be able to compute flow rates, pressures, and viscous losses in laminar and turbulent pipe and duct flows.
      - Understand the connection between boundary layers and drag.
      - Be able to predict the behavior of simple one-dimensional compressible flows.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Basic fluid properties, fundamental concepts, and governing equations; elements of hydrostatics; integral (control volume) governing equations; differential governing equations; inviscid incompressible flow; dimensional analysis, scaling, and nondimensionalization of equations; boundary-layer flow and drag; internal viscous flow; introduction to compressible flow; rudiments of turbulence

1. Course number and name: MENG 363L
Fluid Mechanics and Thermodynamics Laboratory

2. Credits and contact hours: 1.0 credits, 1.3 hours/week + 10 lab sessions throughout the term

3. Instructor's name: Alessandro Gomez

4. Textbooks (title, author, publisher, year): *Fox and McDonald's Introduction to Fluid* Mechanics, 9th edition, by Philip J. Pritchard and John W. Mitchell, John Wiley & Sons, 2015 (same text as for MENG 361), Fundamentals of Engineering Thermodynamics, 8th edition, by M. J. Moran, H. N. Shapiro, D. D. Boettner, and M. B. Bailey, John Wiley and Sons, 2014 (same text as for MENG 211), and Experimentation, Validation, and Uncertainty Analysis for Engineers, 4th edition, by Hugh W. Coleman and W. Glenn Steele, John Wiley and Sons, 2018 (or equivalent text used in PHYS 165L and PHYS 166L).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Hands-on experience in applying the principles of fluid mechanics and thermodynamics. Integration of experiment, theory, and simulation to reflect real-world phenomena. Students design and test prototype devices.

   b. Prerequisites or co-requisites for the course: MENG 211 and 361.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Working in small groups, be able to apply the concepts learned in MENG 211 and 361 to understand, control, and optimize experimental systems.
      - Be able to execute approximately 10 labs in fluid mechanics and thermodynamics and analyze them.
      - Acquire the following technical skills:
        - Ability to perform a calibration;
        - Ability to measure and propagate errors;
        - Ability to use errors to determine how accurate a measurement is or how well a model describes data;
        - Ability to use non-dimensionalization to describe systems with relatively few measurements;
        - Ability to maintain a laboratory notebook as a record of one's work that will aid in archiving results and writing reports;
        - Ability to present data clearly and efficiently in plots to compare datasets or compare data to models; and
        - Ability to communicate technical information accurately, clearly, and concisely in brief reports for each lab and in one full-length publication-style report at the end of the term.

b. Student outcomes addressed by this course:
   - SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
   - SO 3: An ability to communicate effectively with a range of audiences
   - SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
   - SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
   - SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Uncertainty analysis; Joule heating and bomb calorimetry; how to write a lab report; biological combustion: indirect calorimetry; measurement of fluid properties (viscosity and surface tension); Torricelli experiment; Venturi and orifice plate flow meters; gas turbine; pressure drop and velocity profile in pipe flow; single-cylinder IC engine cycle analysis; boundary layer on a flat plate; drag around a sphere using a wind tunnel and drop tube; PEM fuel cell

1. Course number and name: MENG 383
   Mechanical Engineering III: Dynamics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Alex Tsai

4. Textbooks (title, author, publisher, year): Engineering Mechanics: Dynamics, 5^{th} edition, by Anthony Bedford and Wallace Fowler, Prentice-Hall, 2007.
   a. Supplemental materials: Engineering Mechanics: Dynamics, 14^{th} edition, Russell Hibbeler, Pearson Higher Education, Inc., 2016.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      The derivation, analysis, and implementation of numerical methods for the solution of Kinematics and dynamics of particles and systems of particles. Relative motion; systems with constraints. Rigid body mechanics; gyroscopes.

   b. Prerequisites or co-requisites for the course: PHYS 180 or 200, and MATH 120 or ENAS 151.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand and derive equations of motion for particles and rigid bodies.
      - Express equations of motion in various coordinate systems.
      - Apply conservation of energy, impulse and momentum equations to solve for positions, velocities, and accelerations of moving objects for rectilinear and curvilinear motion.
      - Derive and apply equations of motion for systems having rotating and translating axes
      - Be able to solve problems involving relative general plane motion.
      - Predict the motion of systems under free and forced vibrations with and without viscous damping.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 3: An ability to communicate effectively with a range of audiences
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Particle kinetics and kinematics, including: curvilinear motion in Cartesian, normal and tangential, and cylindrical components, relative motion, energy methods, linear and angular momentum, variable mass systems, general rigid-body motion including rotation and translation, moving reference frames, impacts, gyroscopic motion, and the study of systems undergoing viscous and damped vibrations

1. Course number and name: MENG 389
Mechanical Engineering IV: Fluid and Thermal Energy Science

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Ronald Adrezin

4. Textbooks (title, author, publisher, year): Fundamentals of Heat and Mass Transfer, 6th edition, by Frank P. Incropera, David P. DeWitt, Theodore L. Bergman, and Adrienne S. Lavine, John Wiley & Sons, 2006.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Fundamentals of mechanical engineering applicable to the calculation of energy and power requirements, as well as transport of heat by conduction, convection, and radiation.

   b. Prerequisites or co-requisites for the course: MENG 211, 361, and ENAS 194; or permission of instructor.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Introduce the fundamental principles and laws of heat transfer, in solids as well as fluids.
      - Provide the tools necessary to study, analyze and design thermal systems.
      - Develop problem-solving skills necessary to tackle real-world engineering and design problems.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Control surfaces for conduction, convection and radiation; thermal conductivity and material properties; application of the heat equation for 1-D and 2-D steady state conduction with and without generation; application of the heat equation for 1-D and 2-D transient conduction with and without generation; forced external and internal convection; free external convection; radiation and black body applications

1. Course number and name: MENG 390/ENAS 994
   Mechatronics Laboratory

2. Credits and contact hours: 1.0 credits, 2.5 hours/week + 5 lab sessions throughout the term

3. Instructor's name: Madhusudhan Venkadesan

4. Textbooks (title, author, publisher, year): Introduction to Mechatronic Design, by J. Edward Carryer, Matthew Ohline, and Thomas Kenny, Pearson/Prentice-Hall, 2011 and System Dynamics, by Katsuhiko Ogata, 4^{th} edition, Pearson/Prentice-Hall, 2004.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Hands-on synthesis of control systems, electrical engineering, and mechanical engineering. Review of Laplace transforms, transfer functions, software tools for solving ODEs. Review of electronic components and introduction to electronic instrumentation. Introduction to sensors; mechanical power transmission elements; programming microcontrollers; PID control.

   b. Prerequisites or co-requisites for the course: ENAS 194 or equivalent, ENAS 130, and EENG 200; or permission of instructor.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand principles governing microcontrollers, electric circuits, sensors (strain gauges, potentiometers, accelerometers, rotary encoders), actuators (DC motors), and their use in computer-controlled devices.
      - Be able to mathematically analyze, design, and synthesize computer-controlled engineering systems with mechanical and electrical components.
      - Be able to apply lumped-parameter modeling to design and implement single-input, single-output, linear feedback control systems to meet design specifications on stability, settling time, overshoot, steady-state error and other common engineering performance criteria.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Introduction to mechatronic systems; microcontrollers; timers, counters, and interrupts; infrared sensors; system dynamics (electrical circuits, frequency response, phase, time, and feedback); pulse-width modulation and low-pass filters; linear systems; actuators; motors (speed and position control); feedback control (simulating electromechanical systems, PID, state feedback control, stability, and controller tuning); balancing (gyroscopes and accelerometers)

1. Course number and name: MENG 487L
   Mechanical Design: Process and Implementation I

2. Credits and contact hours: 0.5 credits, 4.0 hours/week

3. Instructor's name: Joran Booth

4. Textbooks (title, author, publisher, year): S*higley's Mechanical* Engineering Design, 9th edition, by Richard G. Budynas, J. Keith Nisbett, and Joseph E. Shigley, McGraw-Hill, 2011 (reference text).
   a. Supplemental materials: FE Reference Handbook, NCEES, 2011 and Theory & Design for Mechanical Measurements, 4th edition, by Richard S. Figliola and Donald E. Beasley, John Wiley & Sons, 2006.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      This course is the first half of the capstone design sequence (students take MENG 488 in the spring semester of the same academic year) and is a unique opportunity to apply and demonstrate broad and detailed knowledge of engineering in a team effort to design, construct, and test a functioning engineering system. The lecture portion of the class provides guidance in planning and managing your project, as well other topics associated with engineering design. This course sequence requires quality design; analyses and experiments to support the design effort; and the fabrication and testing of the engineered system; as well as proper documentation and presentation of results to a technical audience.

   b. Prerequisites or co-requisites for the course: MENG 280 and MENG 361. MENG 185 and MENG 325 are strongly suggested.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
      These outcomes are for the two-semester sequence of MENG 487L and MENG 488L.
      - Working in teams, apply and demonstrate broad and detailed knowledge of engineering fundamentals to design, construct, and test a functioning prototype engineering system.
      - Develop the ability to perform analyses/experiments to support the design effort.
      - Be able to implement the following design-related concepts:
        - Start design work early.
        - Iterate on the design often.
        - Treat all documents as "living documents," and update them frequently.
        - Record everything relevant to the project in individual notebooks.
        - Use tests, models, prototypes, etc. to justify ideas.
        - Provide adequate time to complete a task by "sandbagging" the expected time.
        - Work collaboratively with a team.
      - Develop the ability to create a professional-quality presentation to present to a panel of faculty members and external visitors.

b. Student outcomes addressed by this course:
   - SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
   - SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
   - SO 3: An ability to communicate effectively with a range of audiences
   - SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
   - SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
   - SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
   - SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Design as a process (conceptual, preliminary and detailed design phases); developing project scopes; establishing specifications and customer requirements; project planning and budgeting; creative idea generation and selection; decision making techniques; prototype development; engineering safety and hazard analysis; safety considerations and Failure Modes and Effects Analysis (FMEA); power and transmission systems; modelling/analysis; material/component selection. Further topics are covered in MENG 488L.

1. Course number and name: MENG 488L
Mechanical Design: Process and Implementation II

2. Credits and contact hours: 0.5 credits, 4.0 hours/week

3. Instructor's name: Joran Booth

4. Textbooks (title, author, publisher, year): S*higley's Mechanical* Engineering Design, 9th edition, by Richard G. Budynas, J. Keith Nisbett, and Joseph E. Shigley, McGraw-Hill, 2011 (reference text).
   a. Supplemental materials: FE Reference Handbook, NCEES, 2011 and Theory & Design for Mechanical Measurements, 4th edition, by Richard S. Figliola and Donald E. Beasley, John Wiley & Sons, 2006.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
   This course is the second half of the capstone design sequence (students take MENG 487 in the fall semester of the same academic year) and is a unique opportunity to apply and demonstrate broad and detailed knowledge of engineering in a team effort to design, construct, and test a functioning engineering system. The lecture portion of the class provides guidance in planning and managing your project, as well other topics associated with engineering design. This course sequence requires quality design; analyses and experiments to support the design effort; and the fabrication and testing of the engineered system; as well as proper documentation and presentation of results to a technical audience.

   b. Prerequisites or co-requisites for the course: MENG 487, MENG 280, and MENG 361. MENG 185 and MENG 325 are strongly suggested.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course
   a. Specific outcomes of instruction:
   These outcomes are for the two-semester sequence of MENG 487L and MENG 488L.
   - Working in teams, apply and demonstrate broad and detailed knowledge of engineering fundamentals to design, construct, and test a functioning prototype engineering system.
   - Develop the ability to perform analyses/experiments to support the design effort.
   - Be able to implement the following design-related concepts:
     - Start design work early.
     - Iterate on the design often.
     - Treat all documents as "living documents," and update them frequently.
     - Record everything relevant to the project in individual notebooks.
     - Use tests, models, prototypes, etc. to justify ideas.
     - Provide adequate time to complete a task by "sandbagging" the expected time.
     - Work collaboratively with a team.
   - Develop the ability to create a professional-quality presentation to present to a panel of faculty members and external visitors.

b. Student outcomes addressed by this course:
   - SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
   - SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
   - SO 3: An ability to communicate effectively with a range of audiences
   - SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
   - SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
   - SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
   - SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Engineering standards; design for manufacturing; design for assembly; engineering experimentation; engineering ethics; professional responsibility; patents and other intellectual property; engineering communications (including report writing, electronic archiving, and project presentations); product evaluation. Other topics are covered in MENG 487L.

1. Course number and name: MENG 185
   Mechanical Design

2. Credits and contact hours: 1.0 credits, 4.7 hours/week

3. Instructor's name: Rebecca Kramer-Bottiglio

4. Textbooks (title, author, publisher, year): The Mechanical Design Process, 4th edition, by David G.Ullman, McGraw-Hill, 2009 (reference text).
   a. Supplemental materials: Statics and Mechanics of Materials: An Integrated Approach, 2nd edition, by William F. Riley, Leroy D. Sturges, and Don H. Morris, John Wiley & Sons, 2001 (reference text) and Fundamentals of Machine Component Design, 3rd edition, by Robert C. Juvinall and Kurt M. Marshek, John Wiley & Sons, 2000 (reference text).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A course designed for potential majors in mechanical engineering, with units on design methodology, statics, mechanics of materials, and machining. Includes a design project.

   b. Prerequisites or co-requisites for the course: Physics at the level of PHYS 180, or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand and apply a design methodology to open-ended problems.
      - Develop an ability to think creatively and innovatively.
      - Develop improved skills in critical thinking, communication, planning, and scheduling.
      - Gain familiarity with engineering modeling, prototyping, and design realization.
      - Be able to take more advanced courses in the mechanical engineering curriculum.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Design process overview; the House of Quality (HOQ); functional decomposition; concept generation and evaluation; P-Diagrams; intro to models; impact analysis; electric actuators; truss analysis (method of joints and method of sections); design for assembly (DFA); engineering statistics; tolerances; CAD

1. Course number and name: MENG 325
   Machine Elements and Manufacturing Processes

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Joran Booth

4. Textbooks (title, author, publisher, year): S*higley's Mechanical* Engineering Design, 9th edition, by Richard G. Budynas, J. Keith Nisbett, and Joseph E. Shigley, McGraw-Hill, 2011 (reference text).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      This course provides students a working knowledge of two fundamental topics related to mechanical design: machine elements and manufacturing processes. ***Machine elements*** refer to one or more of a range of common design elements that transmit power and enable smooth and efficient motion in mechanical systems with moving parts. This course introduces the most common of these elements and gives students the tools to design systems with them. Topics include common linkages, gearing, bearings, springs, and common actuators such as DC motors. ***Manufacturing processes*** are necessary for the mechanical design engineer to effectively perform her or his duties; they provide an understanding of how the parts and systems that they design are fabricated, allowing "Design for Manufacturing" principles to be taken into account in the product development process. Students learn the basics of common commercial manufacturing processes for mechanical systems, including low-volume processes such as machining to high-volume processes such as casting (metal parts), molding (plastic parts), and stamping (sheet metal parts).

   b. Prerequisites or co-requisites for the course: Extensive CAD experience. MENG 185 and MENG 280 recommended.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Learn and understand the analytical tools necessary to design common machine elements, especially those associated with a drive train.
      - Become familiar with several manufacturing processes and be able to complete physical projects that utilize several manufacturing techniques.
      - Be able to demonstrate the following skills:
        - Design a shaft and avoid fatigue failure.
        - Select properly sized bearings.
        - Select properly sized motors.
        - Select properly sized gears and avoid fatigue failure.
        - Design a gear train for a specified mechanical advantage.
        - Design a compression spring and avoid various failure modes.

- Design a full power train for a complex mechanical system.
- Build, calibrate, and modify an additive manufacturing machine (i.e., 3D printer).
- Identify a wide variety of manufacturing processes in each broad family of manufacturing processes (additive, subtractive, forming, assembly) and how to design for these processes.

b. Student outcomes addressed by this course:

SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

SO 3: An ability to communicate effectively with a range of audiences

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Machine design (shaft and beam fatigue failure analysis; bearing selection; bearing fatigue and failure; motor selection; gear selection and mechanical advantage for gear pairs, compound gear grains, and epicyclic gears; gear tooth forces and gear fatigue analysis; power train design and system-level power analysis; compression spring design and failure modes; kinematic analysis for planar mechanisms) and manufacturing (additive manufacturing; subtractive manufacturing; forming, joining, and assembly processes; surface treatments and coatings)

1. Course number and name: MENG 365
   Chemical Propulsion Systems

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Ronald Lehrach

4. Textbooks (title, author, publisher, year): Mechanics and Thermodynamics of Propulsion, 2nd edition, by Philip Hill and Carl Peterson, Pearson, 1992.
   a. Supplemental materials: In-class notes and additional reference materials provided online.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Study of chemical propulsion systems. Topics include review of propulsion fundamentals; concepts of compressible fluid flow; development and application of relations for Fanno and Rayleigh flows; normal and oblique shock systems to various propulsion system components; engine performance characteristics; fundamentals of turbomachinery; liquid and solid rocket system components and performance.

   b. Prerequisites or co-requisites for the course: MENG 361 or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand the place of various propulsion systems in the flight envelope from low to hypersonic speeds.
      - Be able, from an aero/thermodynamic and compressible fluid flow standpoint, to characterize the performance of system components and integrated system performance.
      - Understand the principles of turbomachinery and liquid- and solid-fueled rocketry, including staging.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Overview of chemical propulsion systems; propulsion fundamentals (conservation laws and the laws of thermodynamics); compressible fluid flow; system components; system performance; liquid- and solid-fueled rockets (including staging)

1. Course number and name: MENG 400/ENAS 600
   Computer-Aided Engineering

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Marshall Long

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: In-class notes and additional reference materials published online.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Aspects of computer-aided design and manufacture (CAD/CAM). The computer's role in the mechanical design and manufacturing process; commercial tools for two- and three-dimensional drafting and assembly modeling; finite-element analysis software for modeling mechanical, thermal, and fluid systems.

   b. Prerequisites or co-requisites for the course: ENAS 130 or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand current trends in the use of computers in design and manufacturing.
      - Introduce the basics of interactive computer graphics, including 3D graphics projections.
      - Become familiar with the use of a state-of-the-art integrated computer-aided design and analysis program.
      - Understand the limitations of computational analysis software.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Computer's role in design and manufacture of a product; interactive computer graphics; use of Computer-Aided Design software packages, including 3D drafting/assembly modeling, motion modeling, finite element analysis and flow analysis; use of Computer-Aided Manufacturing hardware and software; basic finite element methods; limitations of computational analysis software

1. Course number and name: MENG 404/BENG 404
Medical Device Design and Innovation

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Daniel Wiznia and Steven Tommasini

4. Textbooks (title, author, publisher, year): Biodesign: The Process of Innovating Medical Technologies, 2nd edition, by Paul Yock, Stefanos Zenios, Josh Makower, Todd J. Brinton, Uday N. Kumar, F.T. Jay Watkins, Lyn Denend, Thomas M. Krummel, and Christine Q. Kurihara, Cambridge University Press, 2015 (reference text) and Medical Device Design: Innovation from Concept to Market, by Peter J. Ogrodnik, Academic Press, 2013 (reference text).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      The engineering design, project planning, prototype creation, and fabrication processes for medical devices that improve patient conditions, experiences, and outcomes. Students develop viable solutions and professional-level working prototypes to address clinical needs identified by practicing physicians. Some attention to topics such as intellectual property, the history of medical devices, documentation and reporting, and regulatory affairs.

   b. Prerequisites or co-requisites for the course: None.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Become sufficiently familiar with CAD and finite element software to be able to develop finite element models of complex orthopedic surgical problems.
      - Understand how to identify needs within healthcare and the clinical space.
      - Be able to articulate pros and cons of existing standards of practice.
      - Become familiar with regulatory affairs and intellectual property considerations for medical devices.
      - Working in multidisciplinary teams, be able to employ fundamentals of design thinking and the engineering design process to ideate novel solutions to clinical challenges posed by Yale School of Medicine clinicians and medical device company engineers.
      - Develop proof-of-concept prototypes and design experiments to test critical hypotheses.
      - Generate both written and oral deliverables to communicate progress and get feedback from collaborators and mentors.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified

needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

SO 3: An ability to communicate effectively with a range of audiences

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economics, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Aspects of medical device development including problem identification and articulation, needs finding, design process, prototyping, and testing, validation, failure analysis, clinical skills

1. Course number and name: MENG 441/ENAS 441/ENAS 748
Applied Numerical Methods for Differential Equations

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Beth Anne V. Bennett

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Handouts written by the instructor.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      The derivation, analysis, and implementation of numerical methods for the solution of ordinary and partial differential equations, both linear and nonlinear. Additional topics such as computational cost, error estimation, and stability analysis are studied in several contexts throughout the course.

   b. Prerequisites or co-requisites for the course: MATH 115, and MATH 222 or MATH 225, or equivalents; ENAS 130 or some knowledge of Matlab, C++, or Fortran programming; ENAS 194 or equivalent. ENAS 440 is not a prerequisite.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop ability to derive numerical methods and apply them to engineering-related mathematical problems in a way that minimizes computational cost.
      - Develop ability to choose which numerical method to use for a particular problem, based on issues of method efficiency, storage requirements, and likelihood of convergence.
      - Develop ability to question numerical results, to estimate the level of accuracy of the results, and to convey conclusions in written paragraphs with well-supported arguments.
      - Develop ability to solve engineering-related mathematical problems that have no analytical solution (or whose analytical solution is prohibitively complicated to derive), after recasting problems in an appropriate form that involves ordinary differential equations (ODEs) or partial differential equations (PDEs).

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. Brief list of topics to be covered: Numerical solution of ODE initial value problems; numerical solution of ODE boundary value problems; numerical solution of parabolic PDEs; numerical solution of hyperbolic PDEs; numerical solution of elliptic PDEs; computational cost, error estimation, and stability analysis (covered for most numerical solution methods)

1. Course number and name: MENG 459/BENG 459/ENAS 559
   Neuromuscular Biomechanics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Madhusudhan Venkadesan

4. Textbooks (title, author, publisher, year): Muscles, Reflexes, and Locomotion, by Thomas A. McMahon, Princeton University Press, 1984.
   a. Supplemental materials: In-class notes, additional reference materials available online, and journal articles.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Mechanics and control of animal movement, including skeletal muscle mechanics, systems-level neural and sensory physiology, elements of feedback control, and optimal control. Deriving kinematic and kinetic equations for multibody mechanical systems that are actuated by muscles or muscle-like motors; incorporating sensory feedback; analyzing system properties such as stability and energetics.

   b. Prerequisites or co-requisites for the course: MENG 383 and MATH 222 or equivalents, and familiarity with MATLAB or a similar scientific computing environment.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop proficiency in deriving governing equations for the kinematics and kinetics of multibody mechanical systems that are actuated by muscles (or muscle-like motors).
      - Be able to analyze properties such as stability and energetics of multibody mechanical systems.
      - Develop skills to mathematically abstract the dynamics of complex biomechanical systems into ordinary differential equation models.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 3: An ability to communicate effectively with a range of audiences
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

7. Brief list of topics to be covered: Muscle mechanics; kinematics; multibody kinetics; neural control

1. Course number and name: MENG 464/ENAS 787
   Forces on the Nanoscale

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Udo Schwarz

4. Textbooks (title, author, publisher, year): Intermolecular and Surface Forces, 3rd edition, by Jacob Israelachvili, Academic Press, 2011.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Modern materials science often exploits the fact that atoms located at surfaces or in thin layers behave differently from bulk atoms to achieve new or greatly altered material properties. The course provides an in-depth discussion of intermolecular and surface forces, which determine the mechanical and chemical properties of surfaces. In the first part, we discuss the fundamental principles and concepts of forces between atoms and molecules. Part two generalizes these concepts to surface forces. Part three then gives a variety of examples. The course is of interest to students studying thin-film growth, surface coatings, mechanical and chemical properties of surfaces, soft matter including biomembranes, and colloidal suspensions.

   b. Prerequisites or co-requisites for the course: Some knowledge of basic physics, mathematics, chemistry, and thermodynamics is expected.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand how interatomic and intermolecular forces affect the properties of matter (e.g., liquid vs. solid vs. gas, melting, phase separation, ordering, etc.).
      - Understand how intermolecular and surface forces affect properties of surfaces.
      - Become comfortable with discussing and solving problems relating to interatomic/intermolecular forces and surface properties.
      - Attain improved skills for giving and critiquing presentations.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 3: An ability to communicate effectively with a range of audiences
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Energy and energy distributions in multi-particle media; covalent and ionic bonds; interactions involving polar molecules, interactions involving the polarization of molecules, van der Waals forces between atoms and molecules; repulsive

forces and total intermolecular pair potentials; unifying concepts in intermolecular and interparticle forces; contrasts between intermolecular, interparticle, and intersurface forces; van der Waals forces between surfaces; adhesion and contact mechanics; frictional forces; special topics according to students' interest (e.g., thin film growth, surface coatings, membranes, micelles, self-assembly of molecule at surfaces, etc.)

1. Course number and name: MENG 469
   Aerodynamics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Juan Fernandez de la Mora

4. Textbooks (title, author, publisher, year): Fundamentals of Aerodynamics, 5th edition, by John D. Anderson, McGraw-Hill, 2011.
   a. Supplemental materials: Class notes; An Introduction to Fluid Dynamics, G.K. Batchelor, Cambridge University Press, 1967; An Album of Fluid Motion, Milton Van Dyke, The Parabolic Press, 1982.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Review of fluid dynamics. Inviscid flows over airfoils; finite wing theory; viscous effects and boundary layer theory. Compressible aerodynamics: normal and oblique shock waves and expansion waves. Linearized compressible flows.

   b. Prerequisites or co-requisites for the course: MENG 361 or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand lift and drag and various related concepts.
      - Gain a deeper knowledge of fluid dynamics by making use of prior knowledge of vectors, differential equations, and complex calculus.
      - Develop ability to complete open-ended design exercises that make use of the computer software Mathematica.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Review of the governing laws of incompressible inviscid fluid dynamics (vortex theorems, and why and when Euler's equations are applicable); incompressible inviscid aerodynamics (2D airfoils and Prandtl's lifting line wing theory in 3D); lift and drag; airfoil shapes; design of airfoils using Mathematica and Javafoil; viscous

effects; prediction of drag and boundary layer separation (in steady 2D laminar flows); further design of airfoils using Mathematica; compressible flows (mostly adiabatic and 2D); isentropic flows, supersonic expansion waves (Prandtl-Meyer), normal shocks, oblique shocks, airfoils in supersonic flows; linearized supersonic flows

1. Course number and name: MENG 471
   Special Projects I

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Joran Booth

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Lecture slides on various professional skills topics.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. Focus on development of professional skills such as writing abstracts, prospectuses, and technical reports as well as good practices for preparing posters and delivering presentations.

   b. Prerequisites or co-requisites for the course: Permission of adviser and director of undergraduate studies is required.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop the ability to design and outline a plan for solving an engineering problem.
      - Apply knowledge gained in earlier engineering courses to solve an engineering problem (i.e., complete a design or research project) under the supervision of a SEAS adviser.
      - Demonstrate the acquisition of technical writing skills by preparing written project documentation (prospectus, executive summary, and final technical report).
      - Demonstrate the acquisition of technical communication skills by preparing effective slide sets and delivering two well-organized presentations to an audience composed of engineering faculty and fellow undergraduates.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: The professional skills covered include how to write an abstract and a prospectus; how to develop an elevator pitch; how to read a technical report; how to avoid common writing mistakes; how to present data in a meaningful way; how to prepare an effective slide set; how to give a great presentation; how to write an excellent executive summary; and how to write a technical report.

For descriptions of the engineering projects completed in this course in Fall 2019 by B.S. Mechanical Engineering students, please visit https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-471473-projects-2019.

1. Course number and name: MENG 472
   Special Projects I

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Corey O'Hern

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Lecture slides on various professional skills topics.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. Focus on development of professional skills such as writing abstracts, prospectuses, and technical reports as well as good practices for preparing posters and delivering presentations.

   b. Prerequisites or co-requisites for the course: Permission of adviser and director of undergraduate studies is required.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop the ability to design and outline a plan for solving an engineering problem.
      - Apply knowledge gained in earlier engineering courses to solve an engineering problem (i.e., complete a design or research project) under the supervision of a SEAS adviser.
      - Demonstrate the acquisition of technical writing skills by preparing written project documentation (prospectus, executive summary, and final technical report).
      - Demonstrate the acquisition of technical communication skills by preparing effective slide sets and delivering two well-organized presentations to an audience composed of engineering faculty and fellow undergraduates.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: The professional skills covered include how to write an abstract and a prospectus; how to develop an elevator pitch; how to read a technical report; how to avoid common writing mistakes; how to present data in a meaningful way; how to prepare an effective slide set; how to give a great presentation; how to write an excellent executive summary; and how to write a technical report.

For descriptions of the engineering projects completed in this course in Spring 2020 by B.S. Mechanical Engineering students, please visit https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-472474-projects-2020.

1. Course number and name: MENG 473
   Special Projects II

2. Credits and contact hours: 1.0 credits, 1.3 hours/week

3. Instructor's name: Joran Booth

4. Textbooks (title, author, publisher, year): None.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. These courses may be taken at any time during the student's career and may be taken more than once.

   b. Prerequisites or co-requisites for the course: MENG 471 or 472; permission of adviser and director of undergraduate studies.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Extend a design or research project from MENG 471/472 (or complete a new design or research project) under the supervision of a SEAS adviser.
      - Gain further practice in technical writing skills by preparing a prospectus, executive summary, and final technical report.
      - Gain further practice in technical communication skills by giving a final presentation to an audience composed of engineering faculty and fellow undergraduates.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: For descriptions of the engineering projects completed in this course in Fall 2019 by B.S. Mechanical Engineering students, please visit https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-471473-projects-2019.

1. Course number and name: MENG 474
Special Projects II

2. Credits and contact hours: 1.0 credits, 1.3 hours/week

3. Instructor's name: Corey O'Hern

4. Textbooks (title, author, publisher, year): None.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. These courses may be taken at any time during the student's career and may be taken more than once.

   b. Prerequisites or co-requisites for the course: MENG 471 or 472; permission of adviser and director of undergraduate studies.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Extend a design or research project from MENG 471/472 (or complete a new design or research project) under the supervision of a SEAS adviser.
      - Gain further practice in technical writing skills by preparing a prospectus, executive summary, and final technical report.
      - Gain further practice in technical communication skills by giving a final presentation to an audience composed of engineering faculty and fellow undergraduates.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: For descriptions of the engineering projects completed in this course in Spring 2020 by B.S. Mechanical Engineering students, please visit https://seas.yale.edu/departments/mechanical-engineering-and-materials-science/undergraduate-study/me-472474-projects-2020.

1. Course number and name: ENAS 118
   Introduction to Engineering, Innovation, and Design

2. Credits and contact hours: 1.0 credits, 3.7 hours/week

3. Instructor's name: Vincent Wilczynski and Lawrence Wilen

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: SolidWorks Online Tutorial, and Make: Getting Started with Processing, 2nd edition, by Casey Reas and Ben Fry, Maker Media, 2015.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      An introduction to engineering, innovation, and design process. Principles of material selection, stoichiometry, modeling, data acquisition, sensors, rapid prototyping, and elementary microcontroller programming. Types of engineering and the roles engineers play in a wide range of organizations. Lectures are interspersed with practical exercises. Students work in small teams on an engineering/innovation project at the end of the term. Priority to freshmen.

   b. Prerequisites or co-requisites for the course: None.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Gain hands-on experience in a survey of engineering and computer science.
      - Learn select ideas and techniques across disciplines.
      - Apply these ideas and techniques in a team-based final project for a real client.
      - Working as a member of a team, be able to make a working prototype of an original device or system that addresses the needs of the client.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Design as a process; introduction to computer-aided design (CAD); microprocessors; electronics; programming; rapid prototyping; fabrication skills

1. Course number and name: ENAS 400
Making It: Product Design and Entrepreneurship

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Joseph Zinter

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: In-class notes and additional reference materials published online.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Positioned at the intersection of design, technology, and entrepreneurship, students are introduced to the many facets of product design and development while simultaneously working to conceive and develop a marketable product and business.

   b. Prerequisites or co-requisites for the course: Permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand best practices in industrial design, materials selection, fabrication, etc.
      - Develop effective project management and interdisciplinary communication skills.
      - Understand current trends in entrepreneurship and business planning.
      - Understand the design process as it pertains to product creation.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
      SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Introduction to CAD and various rapid prototyping techniques (laser cutting, waterjet cutting, woodworking tools, milling, soldering, electrical testing, etc.); introduction to various concepts in product design, product development, business modeling, and entrepreneurship; communication skills and project documentation; team-based conception and prototyping of a novel product and business strategy

1. Course number and name: ENAS 778
Advanced Robotic Mechanisms

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Aaron Dollar

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Mechanisms and Mechanical Devices Sourcebook, 5th edition, by Neil Sclater, McGraw-Hill, 2011 (reference text), Compliant Mechanisms, by Larry L. Howell, John Wiley & Sons, 2001 (reference text), and Springer Handbook of Robotics, edited by Bruno Siciliano and Oussama Khatib, Springer, 2008 (reference text).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      In-depth coverage of special mechanisms important for advanced robot design. Topics include specialized linkages, modern transmissions (CVTs and harmonic drives), parallel platforms, underactuated mechanisms, variable stiffness mechanisms, cable-driven robots, multi-DOF flexures, and compliant mechanisms. Additional topics may be introduced if time permits. A final design project will be required.

   b. Prerequisites or co-requisites for the course: Undergraduate-level training in machine element design (e.g., MENG 325) or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand and be able to apply concepts associated with advanced robot design.
      - Working in small groups, develop the ability to conceive of, design, analyze, and demonstrate a novel robotic hardware concept.
      - Develop the ability to produce a high-quality paper (of sufficient quality to be submitted to a peer-reviewed conference or journal) on a novel robotic hardware concept.
      - Be able to deliver a professional-quality presentation to a panel of faculty members and visitors.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Linkages and cams; transmissions/reducers; clutches, brakes, and locking mechanisms; underactuated mechanisms; parallel mechanisms; compliant and variable stiffness mechanisms; special topics

1. Course number and name: BENG 350/MCDB 310/MCDB 550/ENAS 550
Physiological Systems

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: W. Mark Saltzman and Stuart Campbell

4. Textbooks (title, author, publisher, year): Medical Physiology, 3rd edition, by Walter Boron and Emile Boulpaep, Elsevier, 2016.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Regulation and control in biological systems, emphasizing human physiology and principles of feedback. Biomechanical properties of tissues emphasizing the structural basis of physiological control. Conversion of chemical energy into work in light of metabolic control and temperature regulation.

   b. Prerequisites or co-requisites for the course: CHEM 165 or 167 (or CHEM 113 or 115), or PHYS 180 and 181; MCDB120, or BIOL 101 and 102.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop a foundation in human physiology by understanding the homeostasis of vital parameters within the body, and the biophysical properties of cells, tissues, and organs.
      - Apply knowledge of chemistry, physics, and biology to human physiology.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Cell and membrane physiology; physical basis of blood flow; mechanisms of vascular exchange, cardiac performance, and regulation of overall circulatory system; respiratory physiology (mechanics of ventilation, gas diffusion, and acid-base balance); renal physiology (formation and composition of urine and the regulation of electrolyte, fluid, and acid-base balance); digestive system (absorption of nutrients and fluid and electrolyte balance); hormonal regulation (applied to metabolic control and to calcium, water, and electrolyte balance); nerve cells (synaptic transmission and simple neuronal circuits within the central nervous system); special senses (considered in the framework of sensory transduction)

1. Course number and name: BENG 351/CENG 351/ ENAS 551
Biotransport and Kinetics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Kathryn Miller-Jensen

4. Textbooks (title, author, publisher, year): None.

a. Supplemental materials: Readings posted on course website from the following textbooks:
   - An Introduction to Systems Biology: Design Principles of Biological Circuits, by Uri Alon, Chapman & Hall/CRC Press, 2007;
   - Receptors: Models for Binding, Trafficking, and Signaling, by Douglas A. Lauffenburger and Jennifer J. Linderman, Oxford University Press, 1993;
   - Drug Delivery: Engineering Principles for Drug Therapy, by W. Mark Saltzman, Oxford University Press, 2001;
   - Transport Phenomena in Biological Systems, 2nd edition, by George A. Truskey, Fan Yuan, and David F. Katz, Prentice Hall, 2009; and
   - Biochemistry, 4th edition, by Donald Voet and Judith G. Voet, John Wiley & Sons, 2011.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
   Creation and critical analysis of models of biological transport and reaction processes. Topics include mass and heat transport, biochemical interactions and reactions, and thermodynamics. Examples from diverse applications, including drug delivery, biomedical imaging, and tissue engineering.

   b. Prerequisites or co-requisites for the course: MATH 115, ENAS 194; BIOL 101 and 102; CHEM 161, 163, or 167; BENG 249.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Learn and understand fundamental principles to quantitatively and critically analyze biomolecular interactions in biological settings.
      - Be able to apply these fundamental principles to solve problems in biology and medicine, including analysis of cellular signaling networks, rational drug design, and strategies for drug delivery.
      - Be able to connect principles covered in this course to other biomedical engineering courses and research tracks.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global,

cultural, social, environmental, and economic factors

7. Brief list of topics to be covered: Protein-ligand binding; thermodynamics of biochemical reactions; isothermal titration calorimetry; binding kinetics; multivalent binding and cooperativity; enzymes (Michaelis-Menten kinetics, regulation, inhibition); time-scale analysis of quasi-steady-state approximation; sensitivity analysis; modeling gene expression; receptor-mediated endocytosis and trafficking; generalized conservation equations for biotransport; diffusion, convection, homogeneous and heterogeneous reactions; transient and steady-state; oxygen transfer and delivery; diffusion in microfluidic biosensors

1. Course number and name: BENG 353/PHYS 353/ENAS 558
Introduction to Biomechanics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Michael P. Murrell

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Readings posted on course website from the following textbooks:
      - An Introduction to Biomechanics: Solids and Fluids, Analysis and Design, by Jay D. Humphrey and Sherry L. O'Rourke, Springer, 2015.
      - Foundations for Biomechanics and Biotransport: A First Course for Biomedical Engineers, by Jay D. Humphrey (PDF handouts).
      - Mechanics of Motor Proteins and the Cytoskeleton, by Jonathon Howard, Sinauer Associates, 2001.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      An introduction to the biomechanics used in biosolid mechanics, biofluid mechanics, biothermomechanics, and biochemomechanics. Diverse aspects of biomedical engineering, from basic mechanobiology to the design of novel biomaterials, medical devices, and surgical interventions.

   b. Prerequisites or co-requisites for the course: PHYS 180, 181, MATH 115, and ENAS 194.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand Navier-Stokes equations and conservation laws in fluid mechanics.
      - Be able to use continuum mechanics to understand cell response to stress in culture.
      - Be able to determine constitutive laws from thermodynamic potentials.
      - Understand how viscometers measure viscosity of viscoelastic materials.
      - Understand first and second laws of thermodynamics.
      - Understand relationships between biomechanics and other areas of biomedical engineering.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. Brief list of topics to be covered: Intermolecular forces; kinematics; elasticity; fluid mechanics; viscoelasticity; poroelasticity; basic thermodynamics; macromolecular mechanics; membrane mechanics; models of cell mechanics; cell behaviors; experimental methods; special topics

1. Course number and name: BENG 405/EVST 415/ENAS 805
Biotechnology and the Developing World

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Anjelica Gonzalez

4. Textbooks (title, author, publisher, year): Biomedical Engineering for Global Health, by Rebecca Richards-Kortum, Cambridge University Press, 2010, and The End of Poverty: Economic Possibilities for Our Time, by Jeffrey Sachs, Penguin Books, 2005.
   a. Supplemental materials: Additional readings from the primary literature.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Study of technological advances that have global health applications. Ways in which biotechnology has enhanced quality of life in the developing world. The challenges of implementing relevant technologies in resource-limited environments, including technical, practical, social, and ethical aspects.

   b. Prerequisites or co-requisites for the course: MCDB 120, or BIOL 101 and 102.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand the impact of biotechnology in the developing world from an engineering perspective.
      - Develop skills necessary for critiquing biotechnology articles from the popular media and the primary literature, including being able to articulate the readings' scientific merit.
      - Develop skills necessary for reviewing biotechnology that has been funded by the Gates Foundation Grand Challenge grants, including being able to discuss the scientific basis of the technology, the target locations, traditional and alternative technologies, and recommendations for the future.
      - Working in teams, complete the preparation of a proposal based on the Gates Foundation Grand Challenge Exploration, including selecting and supporting a strategy incorporating biotechnology, providing an expense report and timeline, and presenting an oral summary of findings.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Overview; introduction to design thinking; biotechnology beyond borders; metrics in global health; healthcare systems; lobbying and policy to face the challenge; vaccinology; delivery of healthcare in neglected populations; anthropological and cultural impacts of biotechnology; research tools; public perception and social impact on adaptation and implementation; cost of technology and who pays for it; sustainable health initiative and global funding; decision-making in a startup; humanitarian efforts (including appropriate design); design-and-build workshop

1. Course number and name: BENG 411/ENAS 711
   BioMEMS and Biomedical Microdevices

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Rong Fan

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Fundamentals of BioMEMS and Medical Microdevices, by Steven S. Saliterman, SPIE Press, 2006 (reference).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Principles and applications of micro- and nanotechnologies for biomedicine. Approaches to fabricating micro- and nanostructures. Fluid mechanics, electrokinetics, and molecular transport in microfluidic systems. Integrated biosensors and microTAS for laboratory medicine and point-of-care uses. High-content technologies, including DNA, protein microarrays, and cell-based assays for differential diagnosis and disease stratification. Emerging nanobiotechnology for systems medicine.

   b. Prerequisites or co-requisites for the course: CHEM 161, 165, or 167 (or CHEM 112, 114, or 118), and ENAS 194.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to design microfabrication workflows to create bioMEMS devices based on the application criteria and conduct quantitative assessment of quality control and performance measures (e.g., feature dimensions, lithography settings, etching conditions, and surface machining).
      - Understand fundamental principles of fluidic mechanics (e.g., Navier-Stokes equations) and transport phenomena (e.g., PNP equations) in microscale fluidic systems, and compute flow velocity profiles in the most widely used bioMEMS systems.
      - Be able to understand, derive, and solve equations in electrokinetic phenomena such as electro-osmosis, electrophoresis and streaming potential.
      - Understand the technology landscape in modern clinical laboratory medicine and the pressing needs that can be tackled by microfabricated tools such as microsensors, microactuators, and point-of-care devices.
      - Understand high-throughput biomolecular and cellular analysis methods and the implementation in quantitative and systems biology.
      - Working as part of a team, complete a design project on any topic in micro- or nanobiotechnology, and submit a report that includes background, significance, design rationale, fabrication (synthesis) procedure, in vitro and in vivo test, clinical test, and/or preparation for FDA evaluation.

b. Student outcomes addressed by this course:

SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

SO 3: An ability to communicate effectively with a range of audiences

SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Overview of bioMEMS; how to make small things; microfluidics (fluid mechanics and electrokinetics in microscales); design and integration of microfluidic circuits; nanofluidics; manipulation of biomolecules and cells; clinical laboratory medicine; biosensors; surface patterning and functionalization; genomic analysis and DNA microarray; next-generation sequencing (NGS); proteomics and protein array; single cell analysis technologies; FDA regulatory process and ISO 10993

1. Course number and name: BENG 434/ENAS 534
Biomaterials

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Anjelica Gonzalez

4. Textbooks (title, author, publisher, year): Biomaterials Science: An Introduction to Materials in Medicine, 3rd edition, by Buddy D. Ratner, Allan S. Hoffman, Frederick J. Schoen, and Jack E. Lemons, Academic Press, 2013, and Introduction to Materials Science for Engineers, 8th edition, by James F. Shackelford, Prentice Hall, 2015.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Introduction to the major classes of biomedical materials: ceramics, metals, and polymers. Their structure, properties, and fabrication connected to biological applications, from implants to tissue-engineered devices and drug-delivery systems.

   b. Prerequisites or co-requisites for the course: CHEM 165 (or CHEM 113 or 115); organic chemistry recommended.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand corrosion and degradation of materials.
      - Calculate stress and strain on bones and tissues during human activity.
      - Determine the elastic moduli of fiber-based materials.
      - Design a hip implant prosthesis, coronary artery, and replacement body tissues.
      - Understand causes of tissue inflammation.
      - Identify key features of stress versus strain relation for brittle materials.
      - Understand nucleation and growth of crystals nuclei in metals.
      - Understand merits of different cryopreservation methods.
      - Design drug delivery systems.
      - Understand the patent process.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. Brief list of topics to be covered: Atomic bonds and crystalline structures; bulk properties; surface properties; mechanical properties of materials; polymeric materials and applications; biomaterials for drug delivery; cellular interactions with biomaterials; bioceramics, bioglass, biocomposites, and applications; metals, composites, and applications; mimicry of natural materials; applications of natural materials

1. Course number and name: CEN G 300
Chemical Engineering Thermodynamics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: T. Kyle Vanderlick

4. Textbooks (title, author, publisher, year): Introduction to Chemical Engineering Thermodynamics, 7th edition, by J.M. Smith, H.C. Van Ness, M.M. Abbott, and M.T. Swihart, McGraw-Hill, 2018.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Analysis of equilibrium systems. Topics include energy conservation, entropy, heat engines, Legendre transforms, derived thermodynamic potentials and equilibrium criteria, multicomponent systems, chemical reaction and phase equilibria, systematic derivation of thermodynamic entities, criteria for thermodynamic stability, and introduction to statistical thermodynamics.

   b. Prerequisites or co-requisites for the course: MATH 120 or ENAS 151 or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand and apply the 1st and 2nd Laws of Thermodynamics.
      - Understand and apply thermodynamic principles of vapor-liquid equilibria.
      - Understand and apply thermodynamic principles of chemical reaction equilibria.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Equilibrium; reversibility; ideal gas; 1st and 2nd Laws of Thermodynamics; phase behavior; fugacity; liquid-vapor equilibria; chemical reaction equilibria

1. Course number and name: CPSC 201
Introduction to Computer Science

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Holly Rushmeier

4. Textbooks (title, author, publisher, year): The Racket Guide (https://docs.racket-lang.org/guide/), by Matthew Flatt, Robert Bruce Findler, and PLT.
   a. Supplemental materials: How to Design Programs: An Introduction to Programming and Computing (https://htdp.org/), 2nd edition, by Matthias Felleisen, Robert Bruce Findler, Matthew Flatt, and Shriram Krishnamurthi, MIT Press (2018).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Introduction to the concepts, techniques, and applications of computer science. Topics include computer systems (the design of computers and their languages); theoretical foundations of computing (computability, complexity, algorithm design); and artificial intelligence (the organization of knowledge and its representation for efficient search). Examples stress the importance of different problem-solving methods.

   b. Prerequisites or co-requisites for the course: After CPSC 112 or equivalent.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand the theoretical foundations of computing.
      - Understand the theoretical foundations of artificial intelligence.
      - Be able to apply programming techniques to design good programs and solve problems.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Functional programming using Racket (syntax, representing and accessing lists, flat and deep recursion, recursion vs. iteration); computability; Turing machines and the halting problem; Boolean functions; logic gates and circuits; von Neumann architecture; programming in machine code, assembly code; abstract data types; regular expressions, DFAs and context-free grammars; compilers; algorithms and complexity analysis

1. Course number and name: CPSC 223
Data Structures and Programming Techniques

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Stanley C. Eisenstat

4. Textbooks (title, author, publisher, year): Notes on Data Structures and Programming Techniques, by James Aspnes, 2018 (available at http://cs.yale.edu/homes/aspnes/classes/223/notes.html), The C Programming Language, 2nd edition, by Brian W. Kernighan and Dennis M. Ritchie, Prentice-Hall, 1988, and Beginning Linux Programming, by Neil Matthew and Richard Stones, 4th edition, John Wiley & Sons, 2008.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Topics include programming in C; data structures (arrays, stacks, queues, lists, trees, heaps, and graphs); sorting and searching; storage allocation and management; data abstraction; programming style; testing and debugging; writing efficient programs.

   b. Prerequisites or co-requisites for the course: After CPSC 201 or equivalent.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to describe how various data structures (arrays, linked lists, stacks, queues, hash tables, trees, and graphs) are represented in memory and used by algorithms.
      - Be able to write programs that use these data structures.
      - Be able to demonstrate different methods for traversing trees.
      - Be able to determine the computational efficiency of the main algorithms for sorting, searching, and hashing.
      - Be able to compare various implementations of data structures (e.g., dynamic vs. static).
      - Be able to apply programming techniques (e.g., modularity, abstract data types, debugging, etc.).

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Programming in C; data structures (arrays, strings, linked lists, stacks, queues, hash tables, binary trees, priority queues, graphs, multiway trees); algorithms (sorting, searching, hashing, storage management, garbage collection, path-finding, minimal spanning trees, string matching); elementary analysis of algorithms and data structures; programming techniques (structured programming and modularity, abstract data types, debugging, testing, verification of program correctness); efficient programming (writing code in different ways and seeing how fast it runs)

1. Course number and name: CPSC 472/CPSC 572
   Intelligent Robotics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Brian M. Scassellati

4. Textbooks (title, author, publisher, year): Vehicles: Experiments in Synthetic Psychology, 2nd edition, by Valentino Braitenberg, MIT Press, 1986, Behavior-Based Robotics, by Ronald C. Arkin, MIT Press, 1998, and Understanding Intelligence, by Rolf Pfeifer and Christian Scheier, MIT Press, 2001.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Introduction to the construction of intelligent, autonomous systems. Sensory-motor coordination and task-based perception. Implementation techniques for behavior selection and arbitration, including behavior-based design, evolutionary design, dynamical systems, and hybrid deliberative-reactive systems. Situated learning and adaptive behavior.

   b. Prerequisites or co-requisites for the course: After CPSC 201 and 202 or equivalents. May not be taken after CPSC 473.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to use math to understand dynamical systems.
      - Be able to design a robotic system that can learn and perceive.
      - Develop an understanding of the societal costs and benefits of intelligent robots.
      - Working as part of a team, be able to design and build a robotic system.
      - Gain the ability to analyze robotic motions.
      - Be able to develop robots with more complex functions and abilities.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
      SO 5: An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

SO 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies

7. Brief list of topics to be covered: Introduction to intelligent, autonomous systems; sensory-motor coordination; task-based perception; behavior-based design; evolutionary design; dynamical systems; hybrid deliberative-reactive systems; situated learning; adaptive behavior

1. Course number and name: EENG 406/ENAS 806
   Photovoltaic Energy

2. Credits and contact hours: 1.0 credits, 2.5 hours/week + 2 lab sessions throughout the term

3. Instructor's name: Fengnian Xia

4. Textbooks (title, author, publisher, year): The Physics of Solar Cells, by Jenny Nelson, Imperial College Press, 2003 (optional text).
   a. Supplemental materials: Materials posted to the course website.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Survey of photovoltaic energy devices, systems, and applications, including review of optical and electrical properties of semiconductors. Topics include solar radiation, solar cell design, performance analysis, solar cell materials, device processing, photovoltaic systems, and economic analysis.

   b. Prerequisites or co-requisites for the course: EENG 320 or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Gain the necessary background and analytical skills to understand established and emerging photovoltaic technologies.
      - Gain familiarity with a diverse range of photovoltaic materials.
      - Connect material properties to aspects of solar cell design, processing, and performance.
      - Be able to complete a final project and presentation that explore both the applications and limitations of photovoltaic technology.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 2: An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
      SO 3: An ability to communicate effectively with a range of audiences
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
      SO 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. Brief list of topics to be covered: Device physics of photovoltaics; statistics of charge carriers in and out of equilibrium; design of solar cells; optical, electrical, and structural properties of semiconductors relevant to photovoltaics

1. Course number and name: G&G 322/G&G 522
Physics of Weather and Climate

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Juan Lora

4. Textbooks (title, author, publisher, year): Atmosphere, Ocean, and Climate Dynamics: An Introductory Text, by John Marshall and R. Alan Plumb, Academic Press, 2008.
   a. Supplemental materials: Global Physical Climatology, 2nd edition, by Dennis Hartmann, Elsevier, 2016 (optional) and Atmospheric Science: An Introductory Survey, 2nd edition, by John Wallace and Peter Hobbs, Academic Press, 2006 (optional).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      The climatic system; survey of atmospheric behavior and climatic change; meteorological measurements and analysis; formulation of physical principles governing weather and climate with selected applications to small- and large-scale phenomena.

   b. Prerequisites or co-requisites for the course: After PHYS 181 and MATH 120 or equivalents.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand the climate system and the physical principles governing the behavior of the atmosphere.
      - Be able to apply mathematical tools to solve problems relating to atmospheric science.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

7. Brief list of topics to be covered: Introduction (atmospheric structure and composition, brief climate history); thermodynamics, convection, and moisture (gas laws, potential temperature, lapse rates, dry and moist convection, boundary layer, Clausius-Clapeyron); global energy balance (energy balance, thermal structure, poleward energy fluxes, greenhouse effect); radiative transfer (radiative transfer equation, grey/semi-grey atmospheres); atmospheric circulation (conservation laws, balanced flow, tropical and extratropical circulations, large-scale atmospheric circulation); climate (climate variability and change, feedbacks, climate sensitivity)

1. Course number and name: G&G 342/PHYS 342
   Introduction to Earth and Environmental Physics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: John Wettlaufer

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Several books were used for reference, including Physics of Climate, by J.P. Peixoto and A.H. Oort, American Institute of Physics, 1992, Dynamical Paleoclimatology, by B. Saltzman, Academic Press, 2002, Physics of the Earth, 4th edition, by F.D. Stacey and P.M. Davis, Cambridge University Press, 2008, and Atmosphere-Ocean Dynamics, by A.E. Gill, Academic Press, 1982.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A broad introduction to the processes that affect the past, present, and future features of the Earth. Examples include climate and climate change and anthropogenic activities underlying them, planetary history, and their relation to our understanding of Earth's present dynamics and thermodynamics.

   b. Prerequisites or co-requisites for the course: PHYS 170, 171, or 180, 181, or 200, 201, or 260, 261, or permission of instructor. Recommended preparation: familiarity with basic calculus and differential equations.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop physical reasoning and quantitative skills (mathematical modeling) in settings that are unique in physics, chemistry, and mathematics.
      - Understand topics of contemporary interest, such as climate change, from the perspective of basic physical interactions.
      - Be able to describe in detail processes such as planetary accretion, the structure of the Earth, the waxing and waning of the ice ages, the circulations of the oceans and atmosphere driving weather and climate, etc.
      - Be able to create and deliver a professional-style presentation surveying a contemporary problem of interest, while linking it to core physical/mathematical concepts covered in the course.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
      SO 4: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

7. Brief list of topics to be covered: Overview; theories of planet formation; diffusion, attraction, collapse; primordial planetary heat, heat transport concepts and mechanisms; the age of Earth, plate tectonics; radiation, heat, and atmospheres; model of Earth's climate; atmosphere and ocean in motion (rotation and convection); simple models of transport processes; the Cryosphere; planetary climate models; carbon cycle; nonlinearity, stability, chaos, and the prediction problem; stochastic processes; climate feedbacks; stochastic resonance

1. Course number and name: PHYS 301
Introduction to Mathematical Methods of Physics

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Oliver K. Baker

4. Textbooks (title, author, publisher, year): Basic Training in Mathematics: A Fitness Program for Science Students, by R. Shankar, Plenum Press, 1995.
   a. Supplemental materials: Mathematical Methods for Physicists, 6th edition, by G.B. Arfken and H.J. Weber, Elsevier, 2005 (recommended).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Topics include multivariable calculus, linear algebra, complex variables, vector calculus, and differential equations. Designed to give accelerated access to 400-level courses by providing, in one term, the essential background in mathematical methods.

   b. Prerequisites or co-requisites for the course: PHYS 170, 171, or 180, 181, or 200, 201, or 260, 261, or permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand and be able to apply the mathematical tools and techniques (in multivariable calculus, linear algebra, complex variables, vector calculus, and differential equations) needed for advanced undergraduate and beginning graduate study in the physical sciences.
      - Gain the necessary background to take more advanced courses on the mathematical methods of physics.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Differential calculus of one variable; integral calculus; calculus of many variables; infinite series; complex numbers; functions of a complex variable; vector calculus; matrices and determinants; linear vector spaces; differential equations

1. Course number and name: S&DS 220/S&DS 520
Introductory Statistics, Intensive

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Joseph Chang

4. Textbooks (title, author, publisher, year): OpenIntro Statistics, 4th edition, by David M. Diez, Mine Çetinkaya-Rundel, and Christopher D. Barr, OpenIntro, 2019 (available at https://www.openintro.org/book/os/).
   a. Supplemental materials: Additional materials available on the course website.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
   Introduction to statistical reasoning for students with particular interest in data science and computing. Using the R language, topics include exploratory data analysis, probability, hypothesis testing, confidence intervals, regression, statistical modeling, and simulation. Computing taught and used extensively, as well as application of statistical concepts to analysis of real-world data science problems.

   b. Prerequisites or co-requisites for the course: MATH 115 is helpful but not required.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Be able to use the language R to analyze and visualize data sets.
      - Be able to use data to make inferences and quantify the certainty of those inferences.
      - Be able to recognize common abuses of statistical methods, such as a too-small sample size and incorrect interpretation of confidence intervals.
      - Gain familiarity with more recent tools of data science, such as graphical network models.

   b. Student outcomes addressed by this course:
   SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Introduction to computing using R; data, statistical inference, distributions, and joint distributions; probability theory (definitions, axioms, counting, conditional probability, Bayes' rule, etc.); random variables, discrete distributions, and continuous distributions; confidence intervals and hypothesis testing; t-distributions and t-tests; inference for categorical data, including chi-square tests; correlation and regression (least squares, multiple regression, R-squared, model selection, etc.); causality

1. Course number and name: S&DS 230/S&DS 530/PLSC 530/F&ES 757
   Data Exploration and Analysis

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Ethan Meyers

4. Textbooks (title, author, publisher, year): None.
   a. Supplemental materials: Readings posted on the course website.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Survey of statistical methods: plots, transformations, regression, analysis of variance, clustering, principal components, contingency tables, and time series analysis. The R computing language and Web data sources are used.

   b. Prerequisites or co-requisites for the course: A 100-level Statistics course or equivalent, or with permission of instructor.

   c. Prerequisite, required, or elective course: Elective

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand extensions of introductory statistics concepts to more complex settings.
      - Learn and understand additional statistics concepts and data science topics.
      - Be able to use various computational methods, and the language R, to analyze and visualize data sets.
      - Be able to communicate results of data analysis clearly and concisely.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Introduction to R; review of central statistical concepts and exploratory analysis using R; confidence intervals and the bootstrap; review of hypothesis tests and permutation tests in R; analysis of variance; multi-factor analysis of variance; simple and multiple regression; logistic regression; data wrangling; data visualization; mapping and joining data; machine learning approaches; miscellaneous additional topics

1. Course number and name: CHEM 163
   Comprehensive University Chemistry I

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: James Mayer

4. Textbooks (title, author, publisher, year): Principles of Modern Chemistry, 8th edition, by David W. Oxtoby, H. Pat Gillis, and Laurie J. Butler, Cengage Learning, 2015.
   a. Supplemental materials: Additional materials posted on course website.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      An in-depth examination of the principles of atomic, molecular, and stolid state chemistry, including structures, periodicity, and chemical reactivity. Topics include the quantum mechanics of atoms and chemical bonding, and inorganic, organic, and solid-state molecules and materials. For students with strong secondary school exposure to general chemistry.

   b. Prerequisites or co-requisites for the course: Enrollment by placement only.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand course topics, which range from the quantum mechanics of atoms and chemical bonding, to inorganic, organic, and solid-state molecules and materials.
      - Develop skills in scientific analysis and inquiry.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Review of basic chemistry; electronic structure: quantum mechanics, atomic structure, and molecular structure; bonding and reactivity through the lens of organic chemistry; polymers; transition metal complexes and solids

1. Course number and name: MATH 112
   Calculus of Functions of One Variable I

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Thomas Hille

4. Textbooks (title, author, publisher, year): Calculus: Early Transcendentals, 8th edition, by James Stewart, Cengage Learning, 2016 (Chapters 2–5 and 9).
   a. Supplemental materials: Homework modules on the course website.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Limits and their properties. Definitions and some techniques of differentiation and the evaluation of definite integrals, with applications. Use of the software package Mathematics to illustrate concepts.

   b. Prerequisites or co-requisites for the course: No prior acquaintance with calculus or computing assumed. May not be taken after MATH 110 or 111.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Gain an understanding of the concepts that underlie the subject in three ways: abstractly (using the language of limits), geometrically, and via some physical interpretations.
      - Be able to apply the concepts in problem solving.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Review of functions and their combinations and graphs, review of trigonometry; exponential function, inverse functions, logarithms; limits and continuity, intermediate value theorem; limits and infinity, asymptotes, tangents, and velocities, derivatives; derivatives of polynomials and exponentials, the product and quotient rules; derivatives of trigonometric functions, the Chain Rule; related rates, linear approximation; maximum and minimum values, the Mean Value Theorem, the derivative and the graph; L'Hopital's Rule, curve sketching; max-min problems, Newton's Method

1. Course number and name: MATH 115
   Calculus of Functions of One Variable II

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Aaron Calderon

4. Textbooks (title, author, publisher, year): Calculus: Early Transcendentals, 8th edition, by James Stewart, Cengage Learning, 2016.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A continuation of MATH 112. Applications of integration, with some formal techniques and numerical methods. Improper integrals, approximation of functions by polynomials, infinite series. Exercises involve the software package Mathematica.

   b. Prerequisites or co-requisites for the course: After MATH 112 or equivalent; open to freshmen with some preparation in calculus. May not be taken after MATH 116.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand how to take complex problems and break them up into simpler ones.
      - Be able to apply concepts of Riemann sums, integration, Taylor series, and parametric and polar equations to solve problems in geometry, economics, biology, and physics.
      - Appreciate the beautiful way that the course topics fit together within the theory of calculus, the mathematics of change.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Antiderivatives; methods to approximate definite integrals and to analyze the error in those approximations; sequences; infinite series; representation of functions with Taylor series; computation of lengths, areas, and volumes of geometric objects; modeling curves using parametric and polar equations

1. Course number and name: MATH 120
   Calculus of Functions of Several Variables

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Marketa Havlickova

4. Textbooks (title, author, publisher, year): Calculus: Early Transcendentals, 8th edition, by James Stewart, Cengage Learning, 2016 (Chapters 12–16).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      Analytic geometry in three dimensions, using vectors. Real-valued functions of two and three variables, partial derivatives, gradient and directional derivatives, level curves and surfaces, maxima and minima. Parametrized curves in space, motion in space, line integrals; applications. Multiple integrals, with applications. Divergence and curl. The theorems of Green, Stokes, and Gauss.

   b. Prerequisites or co-requisites for the course: After MATH 115, or with permission of instructor. May not be taken after MATH 121.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Learn and understand how to use the following concepts:
        - Analytic geometry in three dimensions, using vectors;
        - Real-valued functions of two and three variables, partial derivatives, gradient and directional derivatives, level curves and surfaces, maxima, and minima;
        - Parameterized curves in space, motion in space, line integrals, with applications;
        - Multiple integrals, with applications;
        - Divergence and curl; and
        - The theorems of Green, Stokes, and Gauss.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Vector geometry in three dimensions; vector-valued functions and parametrized curves; scalar functions of multiple variables; partial derivatives; gradients and directional derivatives; constrained optimization; double integrals; polar coordinates; vector fields; line integrals; Green's Theorem; curl and divergence of vector fields; parametrized surface; surfaces integrals; Stokes' Theorem; triple integrals; cylindrical and spherical coordinates and the Divergence Theorem

1. Course number and name: ENAS 151/APHY 151/PHYS 151
Multivariable Calculus for Engineers

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Beth Anne V. Bennett

4. Textbooks (title, author, publisher, year): Calculus: Multivariable, 10th edition, by Howard Anton, Irl Bivens, and Stephen Davis, John Wiley & Sons, Inc., 2012.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      An introduction to multivariable calculus focusing on applications to engineering problems. Topics include vector-valued functions, vector analysis, partial differentiation, multiple integrals, vector calculus, and the theorems of Green, Stokes, and Gauss.

   b. Prerequisites or co-requisites for the course: MATH 115 or equivalent.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Develop ability to use vector-valued functions when working with lines, planes, and surfaces.
      - Develop ability to differentiate, integrate, and apply parametric representations to vector-valued functions in order to compute physical quantities (e.g., position, velocity, and acceleration).
      - Develop ability to perform partial differentiation, including deriving the appropriate form of the Chain Rule.
      - Develop ability to perform double and triple integrals in various coordinate systems in order to compute physical quantities (e.g., average value of a function, mass, center of mass, and centroid).
      - Develop ability to apply multivariable integral theorems to vector-valued functions.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Vector geometry in three dimensions; vector-valued functions and parametrized curves; motion along a curve; scalar functions of multiple variables; partial derivatives and Chain Rule; directional derivatives and gradients; constrained optimization; double integrals; polar coordinates; triple integrals; cylindrical and spherical coordinates; average of a function over a region in 2-space and in 3-space; centers of gravity and mass; vector fields; curl and divergence of vector fields; line integrals; Green's Theorem; parametrization of surfaces; surface integrals; flux; Divergence Theorem; Stokes' Theorem

1. Course number and name: PHYS 180
   University Physics I

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Adriane Steinacker

4. Textbooks (title, author, publisher, year): Fundamentals of Physics, 10th edition, by David Halliday, Robert Resnick, and Jearl Walker, John Wiley & Sons, Inc., 2013.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A broad introduction to classical and modern physics for students who have some previous preparation in physics and mathematics. Fall-term topics include Newtonian mechanics, gravitation, waves, and thermodynamics. Spring-term topics include electromagnetism, special relativity, and quantum physics.

   b. Prerequisites or co-requisites for the course: Concurrently with MATH 115 and 120 or equivalents. May not be taken for credit after PHYS 170, 171.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand course topics, which include Newtonian mechanics, gravitation, waves, and thermodynamics, and be able to apply them in order to solve problems.
      - Develop analytical skills to reduce a complex problem to its simplest parts.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Kinematics; motion in 2D and 3D; uniform circular motion and centripetal acceleration; relative motion; dynamics; friction and drag; energy, power, and work; collisions and momentum; center of mass and applications; rotational motion; rotational dynamics; rotational kinetic energy and angular momentum; Law of Gravity; harmonic oscillator; waves

1. Course number and name: PHYS 181
   University Physics II

2. Credits and contact hours: 1.0 credits, 2.5 hours/week

3. Instructor's name: Adriane Steinacker

4. Textbooks (title, author, publisher, year): Fundamentals of Physics, 10th edition, by David Halliday, Robert Resnick, and Jearl Walker, John Wiley & Sons, Inc., 2013 (Chapters 21–33 and 34 or 37).

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A broad introduction to classical and modern physics for students who have some previous preparation in physics and mathematics. Fall-term topics include Newtonian mechanics, gravitation, waves, and thermodynamics. Spring-term topics include electromagnetism, special relativity, and quantum physics.

   b. Prerequisites or co-requisites for the course: Concurrently with MATH 115 and 120 or equivalents. May not be taken for credit after PHYS 170, 171.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Understand course topics, which include electromagnetism, special relativity, and quantum physics, and be able to apply them in order to solve problems.
      - Develop analytical skills to reduce a complex problem to its simplest parts.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Charges, conductors, insulators, and electrostatic force; electric fields; electric fluc and Gauss's Law, with applications; electric potential; capacitors and capacitance; dielectrics; electric current, resistance, Ohm's Law, resistivity; RC circuits; direct current (DC) circuits; power; electromotive force (EMF); ammeter and voltmeter; magnetic field, Biot-Savart Law, with applications; Lorentz Force; discovery of the electron and elementary charge; electric motors; magnetic flux, Faraday's Law, and Lenz's Law; induction and energy transfer; LC and LR circuits; alternating current (AC) circuits; Maxwell's Equations; the speed of light

1. Course number and name: PHYS 165L
General Physics Laboratory I

2. Credits and contact hours: 0.5 credits, 3 hours/week

3. Instructor's name: Helen Caines

4. Textbooks (title, author, publisher, year): None.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A variety of individually self-contained experiments are roughly coordinated with the lectures in PHYS 170, 171, and 180, 181 and illustrate and develop physical principles covered in those lectures.

   b. Prerequisites or co-requisites for the course: None.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Attain an understanding of the main concepts of physics by direct experience.
      - Understand the role of physics in our personal and professional lives, and in our world.
      - Develop the ability to measure physical quantities and analyze numerical data, including the ability to evaluate measurement uncertainty.
      - Be able to communicate results with others.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Galileo's pendulum (a study in laboratory methods); uncertainties, estimates, and sonograms; accelerated motion (measuring the strength of a fundamental force); terminal velocity; collisions; simple harmonic motion; rotation; gyroscopes; radioactivity; properties of fluids; gas laws (testing Boyle's Law)

1. Course number and name: PHYS 166L
General Physics Laboratory II

2. Credits and contact hours: 0.5 credits, 3 hours/week

3. Instructor's name: Bonnie Fleming

4. Textbooks (title, author, publisher, year): None.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):
      A variety of individually self-contained experiments are roughly coordinated with the lectures in PHYS 170, 171, and 180, 181 and illustrate and develop physical principles covered in those lectures.

   b. Prerequisites or co-requisites for the course: None.

   c. Prerequisite, required, or elective course: Prerequisite

6. Specific goals for the course
   a. Specific outcomes of instruction:
      - Attain an understanding of the main concepts of physics by direct experience.
      - Understand the role of physics in our personal and professional lives, and in our world.
      - Develop the ability to measure physical quantities and analyze numerical data, including the ability to evaluate measurement uncertainty.
      - Be able to communicate results with others.

   b. Student outcomes addressed by this course:
      SO 1: An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

7. Brief list of topics to be covered: Introduction to electronic equipment; simple signals; coupled oscillators; forced damped oscillators and frequency chirp; charge, capacitors, and exponential decay; circuit elements and the circulatory system; electromagnetic induction and EKGs; RLC circuits; geometric optics; diffraction; logic and bio-logic circuits

Appendix B – Faculty Vitae

SEAS Administration

- Prof. Jeffrey Brock, Dean
- Dr. Vincent Wilczynski, Deputy Dean
- Dr. Sarah Miller, Assistant Dean

Yale Mechanical Engineering Ladder Faculty:

- Prof. Charles Ahn
- Prof. Eric Brown
- Prof. Judy Cha
- Prof. Aaron Dollar
- Prof. Juan Fernandez de la Mora
- Prof. Alessandro Gomez
- Prof. Rebecca Kramer-Bottiglio
- Prof. Marshall Long
- Prof. Corey O'Hern
- Prof. Diana Qiu
- Prof. Jan Schroers
- Prof. Udo Schwarz
- Prof. Mitchell Smooke
- Prof. Madhusudhan Venkadesan

Yale Mechanical Engineering Teaching Faculty:

- Dr. Beth Anne Bennett
- Dr. Joran Booth
- Dr. Lawrence Wilen
- Dr. Joseph Zinter

Adjunct Mechanical Engineering Teaching Faculty:

- Dr. Ronald Adrezin
- Dr. Sudhangshu Bose
- Mr. Ronald Lehrach
- Dr. Alex Tsai

Yale Ladder Faculty in Other Departments:

- Prof. Oliver Baker
- Prof. Helen Caines
- Prof. Stuart Campbell
- Prof. Joseph Chang

- Prof. Stanley Eisenstat
- Prof. Rong Fan
- Prof. Bonnie Fleming
- Prof. Anjelica Gonzalez
- Prof. Juan Lora
- Prof. James Mayer
- Prof. Kathryn Miller-Jensen
- Prof. Michael Murrell
- Prof. Mark Reed
- Prof. Holly Rushmeier
- Prof. W. Mark Saltzman
- Prof. Brian Scassellati
- Prof. T. Kyle Vanderlick
- Prof. John Wettlaufer
- Prof. Daniel Wiznia
- Prof. Fengnian Xia

Yale Teaching Faculty in Other Departments:

- Mr. Aaron Calderon
- Dr. Marketa Havlickova
- Dr. Thomas Hille
- Dr. Ethan Meyers
- Dr. Adriane Steinacker
- Dr. Steven Tommasini
- Dr. Thomas VandenBoom

1. Name and academic rank: Jeffrey F. Brock
Dean, School of Engineering & Applied Science,
Dean of Science, Faculty of Arts & Sciences, and
Zhao and Ji Professor of Mathematics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mathematics, University of California, Berkeley, 1997
B.A. Mathematics, Yale University, 1992

3. Academic experience with institution rank and title:
- Zhao and Ji Professor, Mathematics, Yale University, 2019–present
- Dean, School of Engineering & Applied Science, Yale University, 2019–present
- Dean of Science, Faculty of Arts & Sciences, Yale University, 2019–present
- Professor, Mathematics, Yale University, 2018–present
- Visiting Professor (Professeur invité), Université Paul Sabatier, France, 2015
- Visiting Professor (Maître de Conférence invité), Université Paul Sabatier, France, 2010
- Professor, Mathematics, Brown University, 2007–2018
- Associate Professor, Mathematics, Brown University, 2003–2007
- Visiting Professor, University of Texas, Austin, 2003–2004
- Assistant Professor, Mathematics, University of Chicago, 2000–2003
- Szegö Asst. Professor and NSF Postdoc. Fellow, Mathematics, Stanford Univ., 1997–2000

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Mathematical Society (AMS)

7. Honors and awards:
- Sabbatical Fellowship, Simons Foundation, 2016 (declined)
- John Simon Guggenheim Fellowship, 2008
- Donald T. Harrington Faculty Fellowship, UT Austin, 2003–2004
- Alfred P. Sloan Doctoral Dissertation Fellowship, UC Berkeley, 1996–1997
- Outstanding Graduate Student Instructor Award, UC Berkeley, 1996
- NSF Graduate Fellowship, UC Berkeley, 1993–1996

8. Service activities (within and outside Yale):
Within Yale:
- Member, Physical Sciences and Engineering Advisory Committee, 2018–present

Outside Yale:
- Editorial Board, J. Topology, 2018–present
- Scientific Advisory Board, ICERM, Brown University, 2017–present

- Member, Committee on Committees, American Mathematical Society, 2017–2018
- Director, Data Science Initiative, Brown University, 2016–2018
- Co-chair, Search Committee for ICERM Director, Brown University, 2014–2015
- Chair of Mathematics, Brown University, 2013–2017
- Deputy / Associate Director, ICERM, Brown University, 2010–2017
- Director of Undergraduate Studies of Mathematics, Brown University, 2008–2009
- Freshman Adviser, Brown University, 2005–2006
- Colloquium Chair, Mathematics, Brown University, 2004–2006
- Member of various committees at Brown University (Graduate Admissions Cmte., Tenure and Appointments Cmte., Tamarkin Asst. Professor Cmte., Senior Appointments Cmte. Undergraduate Science Education Cmte., Diversity Cmte. for Mathematics, and Steering Cmte. for Brown University Data Science Initiative), 2003–2018

9. Most important publications and/or presentations (last five years):
   - J. Brock, C. Leininger, B. Modami, and K. Rafi, "Limit sets of Teichmüller geodesics with minimal nonuniquely ergodic vertical foliation, II," J. Reine Angew. Math. **2020** (2020) 1–66.
   - J. Brock, C. Leininger, B. Modami, and K. Rafi, "Limit sets of Weil-Petersson geodesics with nonminimal ending laminations," J. Topology and Analysis **12** (2020) 1–28.
   - J. Brock, K. Bromberg, R. Canary, C. Lecuire, and Y. Minsky, "Local topology in deformation spaces of hyperbolic 3-manifolds II," Groups, Geometry, and Dynamics (2019) in press.
   - M. Bridgeman, J. Brock, and K. Bromberg, "Schwarzian derivatives, projective structures, and the Weil-Petersson gradient flow for renormalized volume," Duke Math. J. **168** (2019) 867–896.
   - J.F. Brock and K.W. Brombert, "Correction to 'On the density of geometrically finite Kleinian groups'," Acta Math. **219** (2017) 17–19.
   - K.N. Keshavamurthy, O.P. Leary, L.H. Merck, B. Kimia, S. Collins, D.W. Wright, J.W. Allen, J.F. Brock, and D. Merck, "Machine learning algorithm for automatic detection of CT-identifiable hyperdense lesions associated with traumatic brain injury," Proc. SPIE 10134, Medical Imaging 2017: Computer-Aided Diagnosis, 101342G (March 23, 2017).
   - J.F. Brock and N.M. Dunfield, "Norms on the cohomology of hyperbolic 3-manifolds," Invent. Math. **210** (2017) 531–558.
   - J. Brock and K. Bromberg, "Geometric inflexibility of hyperbolic cone-manifolds," in "Hyperbolic geometry and geometric group theory," Adv. Stud. Pure. Math. **73** (2017) 47–64.

10. Professional development activities:
   - Organizer:
     - Summer@ICERM Undergraduate Research Program, ICERM, Brown Univ., 2017
     - "Geometry and Dynamics in Surfaces and 3-Manifolds II," FRG Conference, 2009
     - "Kleinian groups and Teichmüller Theory, MSRI Program, 2007
     - "Geometry and Dynamics in Surfaces and 3-Manifolds," FRG Conference, 2007
     - "Tameness in Texas," Harrington Conference at UT Austin, 2004
   - NSF-VIGRE REU Instructor, University of Chicago, 2001, 2002 (summers)

1. Name and academic rank: Vincent Wilczynski
Deputy Dean, School of Engineering & Applied Science

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Mechanical Engineering, The Catholic University of America, 1992
M.S.	Mechanical Engineering, Massachusetts Institute of Technology, 1987
M.S.	Naval Architecture and Marine Eng., Massachusetts Institute of Technology, 1987
B.S.	Marine Engineering, U.S. Coast Guard Academy, 1983

3. Academic experience with institution rank and title:
- Deputy Dean, School of Engineering & Applied Science, Yale University, 2010–present
- James S. Tyler Director, Center for Engineering Innovation and Design, Yale University, 2015–present
- Dean of Engineering, U.S. Coast Guard Academy, 2008–2010
- American Council on Education Fellowship for Academic Administration Leadership, 2006–2007
- Chair, Mechanical Engineering, U.S. Coast Guard Academy, 2004–2008
- Professor, Associate Professor, and Assistant Professor, Department of Engineering, U.S. Coast Guard Academy, 1992–2010

4. Non-academic experience:
- Director, FIRST Robotics Competition, Manchester, NH: Responsible for premier industry/university/high school engineering partnership program w/$8 million budget, 40 employees, 1999–2000 (sabbatical leave from USCGA)
- USCG Marine Safety Center Vessel Plan Reviewer: Approved construction blueprints for commercial vessels regulated by the U.S. Coast Guard, 1987–1992
- Assistant Engineer, USCGC Decisive: Engineer, conning officer, and boarding officer for drug enforcement interdictions, 1983–1985

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of American Society of Mechanical Engineers (ASME), American Society for Engineering Education (ASEE), American Council on Education (Fellow 2006/2007), Connecticut Academy of Science and Engineering

7. Honors and awards:
- Connecticut Academy of Science and Engineering (elected to membership), 2012
- U.S. Coast Guard Legion of Merit (for exemplary service as an officer & educator), 2010
- ASME Edwin C. Church Medal (for national contributions in engineering outreach), 2005
- ASME Distinguished Service Award (for effective leadership, prolonged and committed service, devotion, enthusiasm, and faithfulness in the Mechanical Eng. profession), 2003
- U.S. Professor of the Year, Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education, 2001

- U.S. Coast Guard Meritorious Service Medal (for leading institutional accreditation team), 2000

8. Service activities (within and outside Yale):

Outside Yale:

- Vice President, ASME Center for Public Awareness, Board on Pre-College Education, 2004–2010

9. Most important publications and/or presentations (last five years):

- V. Wilczynski, "Contributions of academic makerspaces to design education," in Design Education Today, D. Schaefer, G. Coates, and C. Eckert (eds.), Springer, 2019, 91–114.
- V. Wilczynski, A. Wigner, M. Lande, and S. Jordan, "The value of higher education academic makerspaces for accreditation and beyond," Planning for Higher Education Journal, V46N1 (2017).
- V. Wilczynski and A. McLaughlin, "Similarities and differences between academic centers for entrepreneurship, innovation, and making," Proceedings of the 2nd International Symposium on Academic Makerspaces, 2017.
- V. Wilczynski and A. Hoover, "Classifying academic makerspaces: Applied at ISAM 2017," Proceedings of the 2nd International Symposium on Academic Makerspaces, 2017.
- V. Wilczynski and M.N. Cooke, "Identifying and sharing best practices in international higher education makerspaces," ASEE International Forum, Paper ID #20789, 2017.
- M.J. Maves and V. Wilczynski, "Higher education makerspaces: Engaged students, hands-on skills, interdisciplinary connections," Learning by Design, Spring issue (2017) 16–19.
- P.Z. Ali, M. Cooke, M.L. Culpepper, C.R. Forest, B. Hartmann, M. Kohn, and V. Wilczynski, "The value of campus collaborations for higher education makerspaces," Proceedings of the 1st International Symposium on Academic Makerspaces, 2016
- V. Wilczynski , J. Zinter, and L. Wilen, "Teaching engineering design in an academic makerspace: Blending theory and practice to solve client-based problems," American Society for Engineering Education Annual Conference Proceedings, 2016.
- V. Wilczynski and R. Adrezin, "Higher education makerspaces and engineering education," Proceedings of ASME International Mechanical Engineering Conference & Exposition, 2016.
- V. Wilczynski and S. Slezycki, FIRST Robots: Behind the Design, Chicago, IL, RRDonnelley, 2015.

10. Professional development activities:

- Treasurer, FIRST Foundation, Manchester, NH, 2004–2014
- Committee Member, Naval Engineering in the 21st Century, National Academy of Engineering, Transportation Review Board, Washington, DC, 2009–2011
- NEASC Council on Institutions of Higher Education: Accreditation Member, 1996

1. Name and academic rank: Sarah Miller
Assistant Dean, School of Engineering & Applied Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Chemical & Environmental Engineering, Yale University, 2011
M.Phil. Chemical & Environmental Engineering, Yale University, 2009
M.S. Chemical & Environmental Engineering, Yale University 2007
B.S. Chemistry, Amherst College, 2003

3. Academic experience with institution rank and title:
- Assistant Dean, School of Engineering & Applied Science, Yale University, 2020–present
- Assistant Dean for Inclusive Excellence, College of Engineering & Applied Science, University of Colorado, 2014–2018
- AAAS Science Policy Fellow, National Science Foundation, Arlington, VA, 2011–2014
- Senior Administrator, Roberto Clemente School, New Haven Public Schools, 2011–2012
- Teacher, Teach for America, East Pablo Alto, CA, 2004–2006
- Dean, Green Dean Admission Office Fellowship, Amherst College, 2003–2004

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Chancellor's Employee of the Year, CU Boulder, 2018
- CoNECD Program of the Year, ASEE, 2018
- Advocacy Award, Chancellor's Committee for Women, CU Boulder, 2018
- NEXT Award, NCWIT, 2nd place (with Dr. R. Hoenigman and Ms. A. Parker), 2017
- CU Innovation Award, Intro to Engineering Redesign, 2015
- Pryde Distinguished Alumni Lecturer, Chemistry, Amherst College, 2013
- Elm Ivy Award, City of New Haven & Yale University, 2011
- Associates in Teaching Fellowship, Yale University, 2011
- Advanced Graduate Leadership Program (AGLP) Fellowship, School of Engineering & Applied Science, Yale University, 2009–2010
- NSF Graduate Research Fellowship, 2007–2010
- Japan Memorial Fulbright Fund, 2005

8. Service activities (within and outside Yale):
Within Yale:
- Provost Advisory Committee on Transfer Student Success, 2018–2019
- Graduate Fellow, Saybrook College, 2007–2008

Outside Yale:

- Advisory Board, National Science Foundation, 2018–2019
- Facilitator, “STEM Education and the Innovation Gender Gap,” Women in Innovation Summit, Boulder, CO, March 28, 2016
- Selection Committees at University of Colorado (Alumni Awards, Recent Alumni Award in Engineering, College of Engineering Service Award), 2014–2018

9. Most important publications and/or presentations (last five years):
    - J. Yowell, S.M. Miller, and D. Gruber, “The STEM Core Initiative: An innovative math preparation program for community college students,” National Institute for the Study of Transfer Students (NISTS) Annual Conference, Atlanta, GA, February 13–15, 2019.
    - S.M. Miller, “How to make your advisory board a win-win (and why you should have one in the first place),” Women in Leadership: Higher Education, Cambridge, MA, October 2, 2018.
    - J. Yowell and S.M. Miller, “Alignment of best practices for effective community college transfer,” NISTS Annual Conference, Atlanta, GA, February 7–8, 2018.
    - B. Louie, T. Ennis, C. Lammey, and S.M. Miller, “Leveraging partnerships to foster successful outcomes for students,” National Association of Multicultural Engineering Program Advocates (NAMEPA) National Conference, Blacksburg, VA, September 10–13, 2017.
    - B. Kos and S.M. Miller, “Grade-a-thons and divide and conquer: Effective assessment at scale,” American Society for Engineering Education (ASEE) Annual Conference, Columbus, OH, June 24–28, 2017.
    - S.M. Miller and C. Lammey, “How our institutions support engineers (who also happen to be parents!),” Women in Engineering ProActive Network (WEPAN) Change Leader Forum, Denver, CO, June 14–16, 2017.
    - T. Ennis, B. Myers, J. Milford, S.M. Miller, B. Louie, A. Parker, and C. Lammey, “Redshirting in engineering – The Engineering GoldShirt Program: Creating engineering capacity and expanding diversity,” First-Year Engineering Experience (FYEE) Annual Conference, Columbus, OH, July 31–August 2, 2016.
    - V. Dunn, A. Antoine, S. Swartz, and S.M. Miller, “Effects of a one-week research program on the graduate school pipeline and graduate student professional development,” ASEE Annual Conference, New Orleans, LA, June 26–29, 2016.
    - A. Parker, V. Dunn, and S.M. Miller, “Scholarships! How to do more with less,” WEPAN Change Leader Forum, Denver, CO, June 14–16, 2016.
    - A. Palmer and S.M. Miller, “Student contract to promote inclusion,” WEPAN Change Leader Forum, Denver, CO, June 14–16, 2016.
    - S.M. Miller, “Benefits of a board: How a board of external advisors can advance diversity initiatives within your university,” WEPAN Change Leader Forum, Denver, CO, June 9, 2015.
    - S.M. Miller, “What all high school girls need to know about computing,” Girls Exploring Science, Technology, Engineering, and Math Conference, Denver, CO, May 8, 2015.

10. Professional development activities:
    - Grant reviewer, National Science Foundation, 2012–2018

1. Name and academic rank: Charles H. Ahn
John C. Malone Professor of Applied Physics; Professor of Mechanical Engineering & Materials Science and Physics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Applied Physics, Stanford University, 1996
M.S. Applied Physics, Stanford University, 1996
A.B. Chemistry & Physics, Harvard University, 1989

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- John C. Malone Professor of Applied Physics, 2019–present
- William K. Lanman, Jr., Professor of Applied Physics, Yale University, 2010–2019
- Professor, MEMS and Physics, Yale University, 2010–present
- Professor, Applied Physics and Physics, Yale University, 2007–2010
- Associate Professor, Applied Physics and Physics, Yale University, 2004–2007
- Assistant Professor, Applied Physics and Physics, Yale University, 2000–2004
- Postdoctoral Fellow/Maitre Assistant, University of Geneva, Switzerland, 1996–1999

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Physical Society (APS); Fellow of the Materials Research Society (MRS); Fellow of the American Association for the Advancement of Science (AAAS); Connecticut Academy of Science and Engineering

7. Honors and awards:
- Alfred P. Sloan Fellowship, 2003
- Peter Mark Memorial Award, American Vacuum Society, 2003
- David and Lucile Packard Fellowship in Science and Engineering, 2001
- NSF CAREER, 2001
- Summa cum laude, Harvard University, 1989

8. Service activities (within and outside Yale):
Within Yale:
- Chair, Applied Physics, 2015–present
- Yale Institute for Nanoscience and Quantum Engineering (YINQE), Director
- School of Engineering & Applied Science Cleanroom, Director
- Center for Research on Interface Structures and Phenomena, Director

Outside Yale:
- 27th International Workshop on Oxide Electronics (program committee), 2020
- Editorial board, NPG Quantum Materials and Advanced Materials Interfaces

- Condensed Matter and Materials Research Committee (CMMRC), National Academy of Science

9. Most important publications and/or presentations (last five years):
   - K. Zou, S.D. Albright, O.E. Dagdeviren, M.D. Morales-Acosta, G.H. Simon, C. Zhou, S. Mandal, S. Ismail-Beigi, U.D. Schwarz, E.I. Altman, F.J. Walker, and C.H. Ahn, "Revealing surface-state transport in ultrathin topological crystalline insulator SnTe films," APL Mater. 7 (2019) 051106 (editors' pick).
   - S. Lee, A.T. Lee, A.B. Georgescu, G. Fabbris, M.-G. Han, Y. Zhu, J.W. Freeland, A.S. Disa, Y. Jia, M.P.M. Dean, F.J. Walker, S. Ismail-Beigi, and C.H. Ahn, "Strong orbital polarization in a cobaltate-titanate oxide heterostructure," Phys. Rev. Lett. **123** (2019) 117201.
   - A. Malashevich, M.S.J. Marshall, C. Visani, A.S. Disa, H. Xu, F.J. Walker, C.H. Ahn, and S. Ismail-Beigi, "Controlling mobility in perovskite oxides by ferroelectric modulation of atomic-scale interface structure," Nano Letters **18** (2018) 573–578.
   - M. Dogan, S. Fernandez-Pena, L. Kornblum, Y.C. Jia, D.P. Kumah, J.W. Reiner, Z. Krivokapic, A.M. Kolpak, S. Ismail-Beigi, C.H. Ahn, and F.J. Walker, "Single atomic layer ferroelectric on silicon," Nano Letters **18** (2018) 241.
   - S. Ismail-Beigi, F.J. Walker, A.S. Disa, K.M. Rabe, and C.H. Ahn, "Picoscale materials engineering," Nature Materials Reviews **2** (2017) 17060.
   - A. Disa, A. Georgescu, J. Hart, D. Kumah, P. Shafer, E. Arenholz, D. Arena, S. Ismail-Beigi, M. Taheri, F. Walker, and C. Ahn, "Control of hidden ground-state order in $NdNiO_3$ superlattices," Phys. Rev. Materials **1** (2017) 024410.
   - K. Zou, S. Mandal, S. Albright, R. Peng, Y. Pu, D. Kumah, C. Lau, G. Simon, O. Dagdeviren, X. He, I. Božović, U. Schwarz, E. Altman, D. Feng, F. Walker, S. Ismail-Beigi, and C. Ahn, "Role of double TiO2 layers at the interface of FeSe/SrTiO3 superconductors," Phys. Rev. B **93** (2016) 180506(R).
   - D. Kumah, M. Dogan, J. Ngai, D. Qiu, Z. Zhang, D. Su, E.D. Specht, S. Ismail-Beigi, C. Ahn, and F. Walker, "Engineered unique elastic modes at a BaTiO3/(2×1)-Ge(001) interface," Phys. Rev. Lett. **116** (2016) 106101.
   - G. Fabbris, D. Meyers, J. Okamoto, J. Pelliciari, A.S. Disa, Y. Huang, Z.-Y. Chen, W.B. Wu, C.T. Chen, S. Ismail-Beigi, C.H. Ahn, F.J. Walker, D.J. Huang, T. Schmitt, and M.P.M. Dean, "Orbital engineering in nickelate heterostructures driven by anisotropic oxygen hybridization rather than orbital energy levels," Phys. Rev. Lett. **117** (2016) 147401.
   - I. Bozovic and C. Ahn, "A new frontier for superconductivity," Nature Physics **10** (2014) 892.
   - C. Xiong, W.H.P. Pernice, J.H. Ngai, J.W. Reiner, D. Kumah, F.J. Walker, C.H. Ahn, and H.X. Tang, "Active silicon integrated nanophotonics: Ferroelectric BaTiO3 devices," Nano Letters **14** (2014) 1419.

10. Professional development activities:
    - Reviewer for peer-reviewed journals
    - Chair of technical sessions at international and U.S. conferences

1. Name and academic rank: Eric M. Brown
   Assistant Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Physics, University of California, Santa Barbara, 2007
   B.S. Physics, Harvey Mudd College, 2002

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Assistant Professor, 2013–present
   - Assistant Professor, School of Natural Sciences, Univ. of California, Merced, 2011–2013
   - Postdoctoral Scholar, James Franck Institute, University of Chicago, 2007–2011

4. Non-academic experience:
   - Patents:
     - H. Lipson, J.R. Amend, Jr., H. Jaeger, and E. Brown, "Gripping and releasing apparatus and method," US Patent 9,120,230 B2, issued Sept. 1, 2015.
     - H. Lipson, J. Amend, H. Jaeger, and E. Brown, "Gripping and releasing apparatus and method," US Patent 8,882,165 B2, issued Nov. 11, 2014.

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Physical Society (APS), American Geophysical Union (AGU)

7. Honors and awards:
   - NSF CAREER, 2013
   - Kadanoff-Rice Postdoctoral Fellowship, 2007
   - UC Santa Barbara Circus Award for Outreach, 2003–2005
   - Harvey S. Mudd Merit Award, 2002

8. Service activities (within and outside Yale):
   Within Yale:
   - Public lecture and cornstarch pool demonstration at Science Saturdays, 2014
   - Project mentor for undergraduate theses and summer research experiences, 2013–present
   - Developed materials for scientific method education, 2013

   Outside Yale:
   - Provided technical expertise for PBS documentary on animal homes, 2015
   - Project mentor for undergraduate theses and summer research experiences at University of Chicago, 2008–2011, and UC Merced, 2011–2013
   - Organizer for Computations in Science seminar series, University of Chicago, 2008–2009

- Organizer for Physics Circus outreach to elementary school students, UC Santa Barbara, 2002–2007

9. Most important publications and/or presentations (last five years):
    - R. Maharjan, E. O'Reilly, T. Postiglione, N. Klimenko, and E. Brown, "Intermittent dilation and its coupling to stress in discontinuous shear thickening suspensions," Apr. 29, 2020, arxiv:2004.14316v1[cond-mat.soft].
    - D. Ji and E. Brown, "Oscillation in the temperature profile of the large-scale circulation of turbulent convection induced by a cubic container," Feb. 28, 2020, arxiv:2003.00067v1 [physics.flu-dyn].
    - D. Ji and E. Brown, "Low-dimensional model of the large-scale circulation of turbulent Rayleigh-Bénard convection in a cubic container," Dec. 25, 2019, arxiv:1912.11724v1 [physics.flu-dyn].
    - R. Maharjan and E. Brown, "Effective packing fraction for better resolution near the critical point of shear thickening suspensions," Phys. Rev. E **99** (2019) 042604.
    - O. Ozgen, M. Kallman, and E. Brown, "An SPH model to simulate the dynamic behavior of shear thickening fluids," Computer Animation & Virtual Worlds **30** (2019) e1870.
    - K. Bai, J. Casara, A. Nair-Kanneganti, A. Wahl, F. Carle, and E. Brown, "Effective magnetic susceptibility of suspensions of ferromagnetic particles," J. Applied Physics **124** (2018) 123901.
    - S. Mukhopadhyay, B. Allen, and E. Brown, "Testing constitutive relations by running and walking on cornstarch and water suspensions," Phys. Rev. E **97** (2018) 052604.
    - B. Allen, B. Sokol, S. Mukhopadhyay, R. Maharjan, and E. Brown, "Structure of the system spanning dynamically jammed region in response to impact of cornstarch and water suspensions," Phys. Rev. E **97** (2018) 052603.
    - R. Maharjan, S. Mukhopadhyay, B. Allen, T. Storz, and E. Brown, "Constitutive relation of the dynamically jammed region in response to impact of cornstarch and water suspensions," Phys. Rev. E **97** (2018) 052602.
    - R. Maharjan and E. Brown, "Giant deviation of a relaxation time from generalized Newtonian theory in discontinuous shear thickening suspensions," Phys. Rev. Fluids **2** (2017) 123301.
    - F. Carle, K. Bai, J. Casara, K. Vanderlick, and E. Brown, "Development of magnetic liquid metal suspensions for magnetohydrodynamics," Phys. Rev. Fluids **2** (2017) 013301.
    - K. Bai, D. Ji, and E. Brown, "Ability of a low-dimensional model to predict geometry-dependent dynamics of large-scale coherent structures in turbulence," Phys. Rev. E **93** (2016) 023117.
    - Q. Xu, S. Majumdar, E. Brown, and H. M. Jaeger, "Shear thickening in highly viscous granular suspensions," Euro. Phys. Lett. **107** (2014) 68004.

10. Professional development activities:
    - Reviewer for several peer-reviewed scientific journals
    - Grant reviewer for Petroleum Research Fund

1. Name and academic rank: Judy J. Cha
Carol & Douglas Melamed Associate Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Physics, Cornell University, 2009
B.A.Sc. Physics, Simon Fraser University, Canada, 2003

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Carol & Douglas Melamed Associate Professor, 2019–present
- Carol & Douglas Melamed Assistant Professor, 2015–2019
- Assistant Professor, 2013–2019
- Postdoctoral Associate, Materials Science and Engineering, Stanford Univ., 2009–2013

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Materials Research Society (MRS), American Physical Society (APS), American Chemical Society (ACS)

7. Honors and awards:
- Moore Foundation EPiQS Materials Synthesis Investigator Award, 2019
- Young Innovator Award in Nano Energy by Nano Research, 2019
- NSF CAREER, 2018
- 4th Hanwha Non-Tenured Faculty Award, 2018
- CIFAR Azrieli Global Scholar for Quantum Materials, 2017
- Yale Arthur Greer Memorial Prize, 2016
- Carol & Douglas Melamed Assistant Professor Chairship, Yale University, 2015
- IBM Faculty Award, 2014
- Presidential Student Award, Microscopy Society of America, 2010 and 2006
- Silver Student Award, Materials Research Society, 2008
- Distinguished Scholar Award, Microbeam Analysis Society, 2008
- NSERC of Canada Undergraduate Student Research Award, 2002

8. Service activities (within and outside Yale):
Outside Yale:
- External user proposal reviewer, Cornell Materials Innovation Platform PARADIM, 2016–present
- Reviewer of DOE proposals, 2016–present
- Proposal panel reviewer, National Science Foundation, 2015–present
- Proposal reviewer, Ctr for Functional Nanomaterials, Brookhaven Natl. Lab, 2014–present

9. Most important publications and/or presentations (last five years):

- Y. Zhou, J.V. Pondick, J. Luis Silva, J.M. Woods, D.J. Hynek, G. Matthews, X. Shen, Q. Feng, W. Liu, Z. Lu, Z. Liang, B. Brena, Z. Cai, M. Wu, L. Jiao, S. Hu, H. Wang, C.M. Araujo, and J.J. Cha, "Unveiling the interfacial effects for enhanced hydrogen evolution reaction on MoS_2/WTe_2 hybrid structures," Small **15** (2019) 1900078.
- P. Liu, J.R. Williams, and J.J. Cha, "Topological nanomaterials," Nature Reviews Materials **4** (2019) 479–496.
- Y. Xie, S.W. Sohn, M. Wang, H. Xin, Y. Jung, M.D. Shattuck, C.S. O'Hern, J. Schroers, and J.J. Cha, "Supercluster-coupled growth in metallic glass forming liquids," Nature Communications **10** (2019) 915.
- Y. Zhou, J. Luis Silva, J.M. Woods, J.V. Pondick, Q. Feng, Z. Liang, W. Liu, L. Lin, B. Deng, B. Brena, F. Xia, H. Peng, Z. Liu, H. Wang, C.M. Araujo, and J.J. Cha, "Revealing the contribution of individual factors to hydrogen evolution reaction catalytic activity," Advanced Materials **30** (2018) 1706076.
- Y. Xie, W. Kim, Y. Kim, S. Kim, M. BrightSky, Y. Zhu, C. Lam, and J. J. Cha, "Self-healing of a confined phase change memory cell with a metallic surfactant layer," Advanced Materials **30** (2018) 1705587.
- S.W. Sohn, Y. Xie, Y. Jung, J. Schroers, and J.J. Cha, "Tailoring crystallization phases in metallic glass nanorods via nucleus starvation," Nature Communications **8** (2017) 1980.
- P. Kumaravadivel, G. Pan, Y. Zhou, Y. Xie, P. Liu, and J.J. Cha, "Synthesis and superconductivity of In-doped SnTe nanostructures," APL Materials **5** (2017) 076110.
- B. Deng, V. Tran, Y. Xie, H. Jiang, H. Tian, Q. Guo, X. Wang, J.J. Cha, H. Wang, Q. Xia, L. Yang, and F. Xia, "Efficient electrical control of thin-film black phosphorus bandgap," Nature Communications **8** (2017) 14474.
- Y. Zhou, H. Jang, J.M. Woods, Y. Xie, P. Kumaravadivel, G.A. Pan, J. Liu, Y. Liu, D.G. Cahill, and J.J. Cha**,** "Direct synthesis of large-scale WTe_2 thin films with low thermal conductivity," Advanced Functional Materials **27** (2017) 1605928.
- S.W. Sohn, Y. Jung, Y. Xie, C. Osuji, J. Schroers, and J.J. Cha, "Nanoscale size effects in crystallization of metallic nanorods," Nature Communications **6** (2015) 8157.
- J. Shen, Y. Xie, and J.J. Cha, "Revealing surface states in In-doped SnTe nanoplates with low bulk mobility," Nano Letters **15** (2015) 3827–3832.
- Y. Liu, J. Liu, S. Sohn, Y. Li, J.J. Cha, and J. Schroers, "Metallic glass nanostructures of tunable shape and composition," Nature Communications **6** (2015) 7043.

10. Professional development activities:

- Co-organizer of the 2019 MRS Fall meeting on the 2D materials symposium, 2019
- Co-organizer of the 2019 Microscopy and Microanalysis meeting on in situ TEM, 2019
- Member of the editorial advisory board for APL Materials, 2017–present
- Co-chair at the DOE ECMP PI review meeting, 2017
- Co-organizer, APS Focus Topic, APS March Meeting, 2017 and 2013
  – "Topological Materials: Synthesis, Characterization, and Modeling"
- Chair of the technical session on bulk metallic glasses at TMS, 2016
- 63rd AVS conference, 2D Materials Focus Topic Committee, 2016
- Frequent reviewer for journals in physics, materials science, energy, and chemistry

1. Name and academic rank: Aaron M. Dollar
Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Engineering Sciences, Harvard University, 2007
   - S.M. Engineering Sciences, Harvard University, 2002
   - B.S. Mechanical Engineering, University of Massachusetts, Amherst, 2000

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Professor, 2019–present
   - Associate Professor, 2016–2019
   - John J. Lee Associate Professor, 2014–2015
   - John J. Lee Assistant Professor, 2012–2013
   - Assistant Professor, 2009–2012
   - Postdoctoral Associate, Health Sciences and Technology, Massachusetts Institute of Technology, 2006–2008

4. Non-academic experience:
   - Engineering intern, Hamilton Sundstrand, 1999–2000

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Society of Mechanical Engineers (ASME); Institute for Electrical and Electronics Engineers (IEEE), Senior Member

7. Honors and awards:
   - UMass Amherst College of Engineering Outstanding Junior Alumni Award, 2016
   - Best Poster, Observing and Understanding Hands in Action Workshop (Hands 2015), at the Computer Vision and Pattern Recognition Conference (CVPR), 2015
   - NASA Early Career Faculty (ECF) Award, 2014
   - DARPA Young Faculty Award, 2013
   - First place in DARPA's Autonomous Robotic Manipulation-Hardware (ARM-H) Competition (partner with Harvard University and iRobot Corporation), 2012
   - AFOSR Young Investigator Award, 2011
   - TR35, Technology Review's Top Young Innovators under 35, 2010
   - NSF CAREER Award, 2010

8. Service activities (within and outside Yale):
   Within Yale:
   - Chair, University-wide Student Shop Safety Committee, 2013–present
   - Member of other University-wide committees (e.g., Safety Cmte., Science Strategy Cmte., Center for Engineering Innovation and Design Faculty Advisory Cmte., ITS Focus Group)

- Chair of several departmental committees (e.g., Mechatronics/Robotics Search Cmte., Design Lecturer Search Cmte., Curriculum Cmte.)

Outside Yale:

- Founder and editor of robotics resources (Yale/CMU/Berkeley Object and Task Set, 2015–present; OpenRobotHardware.org, 2013–present; Yale OpenHand Project; RoboticsCourseWare.org, 2008–present)
- Organizer/speaker at public outreach events (e.g., keynote lecturer, Eli Whitney Museum; speaker, Essex Public Library's Science for Everyone program; speaker, PBS/NOVA-sponsored "Science Café"; co-organizer of 250-student Robotics Workshop)
- Lab tours and demos for Cub Scouts, middle-schoolers, etc.

9. Most important publications and/or presentations (last five years):
   - K. Hang, W. Bircher, A. Morgan, and A.M. Dollar, "Hand-object configuration estimation using particle filters for dexterous in-hand manipulation," Int. J. Robot. Res., in press.
   - R.R. Ma, W. Bircher, and A.M. Dollar, "Modeling and evaluation of robust, whole-hand caging manipulation," IEEE Trans. Robot. **35** (2019) 549–563.
   - A.Sintov, A. Morgan, A. Kimmel, A.M. Dollar, K.E. Bekris, and A. Boularias, "Learning a state transition model of an underactuated adaptive hand," IEEE Robot. Autom. Lett. **4** (2019) 1287–1294.
   - D. Sustaita, Y. Gloumakov, L.R. Tsang, and A.M. Dollar, "Behavioral correlates of semi-zygodactyly in ospreys (pandion haliaetus) based on analysis of internet images," PeerJ **7** (2019) e6243.
   - B. Calli and A.M. Dollar, "Robust precision manipulation with simple process models using visual servoing techniques with disturbance rejection," IEEE Trans. Autom. Sci. Eng. **16** (2019) 406–419.
   - A.J. Spiers, B. Calli, and A.M. Dollar, "Variable-friction finger surfaces to enable within-hand manipulation via gripping and sliding," IEEE Robot. Autom. Lett. **3** (2018) 4116–4123.
   - A.I. Nawroj, J.P. Swensen, and A.M. Dollar, "Toward modular active-cell robots (MACROs): SMA cell design and modeling of compliant, articulated meshes," IEEE Trans. Robot. **33** (2017) 796–806.
   - B. Calli, A. Singh, J. Bruce, A. Walsman, K. Konolige, S. Srinivasa, P. Abbeel, and A.M. Dollar, Yale-CMU-Berkeley dataset for robotic manipulation research," Int. J. Robot. Res. **36** (2017) 261–268.

10. Professional development activities:
    - Mgmt. Cmte., IEEE/ASME Trans. on Mechatronics, 2016-present; Chair, 2019
    - Founding Chair, IEEE Robotics and Automation Society Technical Committee on Mechanisms and Design, 2014–present
    - Associate Editor, ASME J. Mechanisms and Robotics, 2013–2017
    - Chair for numerous symposia, workshops, and tutorials (national and international)
    - Associate Editor for several IEEE international conference proceedings (ICRA 2012, 2013, 2014; IROS, 2013, and BioRob, 2012)
    - Editor for special issues of various robotics journals

1. Name and academic rank: Juan Fernandez de la Mora
Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Engineering & Applied Science, Yale University, 1981
   B.S. Aeronautical Engineering, Polytechnical University, Madrid, 1975

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Professor, 1992–present
   - "Profesor Titular" of Physics, Universidad Nacional de Educación a Distancia (Open University), 1988–1991
   - Visiting Professor, School of Aeronautical Engineering, Madrid, 1987–1988
   - Associate Professor, 1986–1992
   - Assistant Professor, 1981–1986
   - Postdoctoral Scholar, University of California at Los Angeles, 1981

4. Non-academic experience:
   - Recent patents (14 granted since 1999):
     - J. Fernandez de la Mora, "High resolution mobility analysis of large charge-reduced electrospray ions," US Patent 10,163,615, issued Dec. 25, 2018.
     - M. Amo, D. Zamora, Casado, A., G. Fernandez de la Mora, G. Vidal-de-Miguel, and J. Fernandez de la Mora, "Method for detecting atmospheric vapors at parts per quadrillion (ppq) concentrations," US Patent 9,297,785, issued Mar. 29, 2016.
     - P. Martinez-Lozano Sinues and J. Fernandez de la Mora, "Method to analyze and classify persons and organisms based on odor patterns from released vapors," US Patent 9,121,844B, issued Sept. 1, 2015.
   - Consulting: IBM, Hewlett Packard, Schmitt Technology (later Jet Process Corp.), Analytica of Branford, Universidad Carlos III (Madrid), Nanoengineering, SEADM (Madrid), Busek, Connecticut Analytical Corp., Rohm & Haas, Synergy Innovations, RAMEM (Madrid), ILIA (Madrid), TSI
   - Co-founder: Jet Process Corp., NanoEngineering, SEADM, SEDET, Using Best Tools

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Connecticut Academy of Science and Engineering, Connecticut Academy of Arts and Sciences, American Chemical Society (ACS), European Aerosol Association, American Association for Aerosol Research (AAAR)

7. Honors and awards:
   - Sinclair Award from the American Association of Aerosol Research, 2006
   - Corresponding Member, Spanish Academy of Engineering, 1998
   - Research fellow, Japan Society for Promotion of Science, 1996
   - K. Whitby Award from the American Association of Aerosol Research, 1985

- Yale Junior Faculty Fellowship, 1984
- Harding Bliss Graduate Prize, Yale University, 1981

8. Service activities (within and outside Yale):
 Outside Yale:
 - Board of Directors, Fundación Nacional Francisco Franco, Madrid, 2017–present
 - Board of Directors, Fundación Balmes, Madrid, 2007–present
 - Editorial Board, *Journal of Aerosol Science*, 2000–2003
 - Board of Directors, American Association for Aerosol Research, 1999–2002

9. Most important publications and/or presentations (last five years):
 - J. Fernández García, S. Compton, C. Wick, and J. Fernandez de la Mora, "Virus size analysis by gas phase mobility measurements: Resolution limits," *Anal. Chem.* **91** (2019) 12962–12970.
 - M. Arias-Zugasti, D.E. Rosner, and J. Fernandez de la Mora, "Low Reynolds number capture of small particles on a cylinder by diffusion, interception and inertia at subcritical Stokes numbers: Numerical calculations, correlations, and small diffusivity asymptote," *Aerosol Sci. Tech.* **53** (2019) 1367–1380.
 - J. Fernandez de la Mora, "Space charge effects in ion mobility spectrometry," *J. American Soc. Mass Spectrom.* **30** (2019) 1082–1091.
 - J. Fernandez de la Mora and D.E. Rosner, "Low Reynolds number capture of small particles on cylinders by diffusion, interception and inertia at subcritical Stokes numbers," *Aerosol Sci. Tech.* **53** (2019) 647–662.
 - J. Fernandez de la Mora, "Mobility analysis of proteins by charge-reduction in a bipolar electrospray source," *Anal. Chem.* **90** (2018) 12187–12190.
 - M. Amo-González, I. Carnicero, S. Pérez, R. Delgado, G. A. Eiceman, G. Fernández de la Mora, and J. Fernández de la Mora, "Ion mobility spectrometer-fragmenter-ion mobility spectrometer analogue of a triple quadrupole for high-resolution ion analysis at atmospheric pressure," *Anal. Chem.* **90** (2018) 6885–6892.
 - D. Zamora, M. Amo-Gonzalez, M. Lanza, G. Fernandez de la Mora, and J. Fernandez de la Mora, "Reaching a vapor sensitivity of 0.01 parts per quadrillion in the screening of large volume freight," *Anal. Chem.* **90** (2018) 2468–2474.
 - Madden, J. Fernandez de la Mora, B. Hawkett, and N. Jain, "Effect of a homogeneous magnetic field on the electrospraying characteristics of sulfolane ferrofluids," *J. Fluid Mech.* **833** (2017) 430–444.
 - J. Fernandez de la Mora and C. Barrios, "A bipolar electrospray source of singly charged salt clusters of precisely controlled composition," *Aerosol Sci. Tech.* **51** (2017) 778–786.
 - M. Amo-Gonzalez and J. Fernandez de la Mora, "High dynamic range differential mobility analyzer (DMA) coupled with a mass spectrometer and several ionization sources," *J. American Soc. Mass Spectrom.* **28** (2017) 1506–1517.

10. Professional development activities:
 - Recently entered new field of high resolution gas phase identification of viral particles
 - Recently entered field of particle sizing via heterogeneous condensation

1. Name and academic rank: Alessandro Gomez
Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Mechanical & Aerospace Engineering, Princeton University, 1986
   - M.A. Mechanical & Aerospace Engineering, Princeton University, 1982
   - Laurea Aeronautical Engineering, University of Naples, Italy, 1980

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Professor, 1998–present
   - Director of the Yale Center for Combustion Studies, 1994–present
   - Associate Professor, 1993–1998
   - Assistant Professor, 1989–1993
   - Lecturer, 1988
   - Postdoctoral Research Associate, 1986–1987

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: European Union Academy of Sciences, Connecticut Academy of Science and Engineering, Fellow of the Combustion Institute, American Association for Aerosol Research (AAAR)

7. Honors and awards:
   - Whitby Award from the American Association for Aerosol Research, 1996
   - Barton Weller Associate Professor of Mechanical Engineering, 1995–1998
   - NSF Young Investigator Award, 1992
   - Fulbright Scholarship, 1980–1981
   - Summa cum laude, University of Naples, 1980
   - Associazione Tecnica dell Automobile Scholarship, 1979–1980
   - Von Karman Institute of Fluid Mechanics Scholarship, 1979–1980

8. Service activities (within and outside Yale):
   Within Yale:
   - Faculty Senate, 2019–2021
   - Steering Committee of Yale Climate and Energy Institute (YCEI)
   - Steering Committee of the Energy Institute
   - Chair of Departmental Energy Search Committee
   - Chair of Departmental Energy Broad Search Committee in areas of materials and fluids
   - Chair of Departmental Search in Fluid Mechanics, 2018
   - Director of Graduate Studies for Engineering & Applied Science, 1999–2002

Outside Yale:

- Associate Editor of Combustion Science and Technology, 2007–2012
- Organizing Committee of International Combustion Symposium (Spray Section)
- Program Committee, Aerosol Technology

9. Most important publications and/or presentations (last five years):

- K. Gleason, F. Carbone, and A. Gomez, "Pressure and temperature dependence of soot in highly controlled counterflow ethylene diffusion flames," Proc. Combust. Inst. **37** (2019) 2057–2064.
- J. Tang, H. Wang, and A. Gomez, "Controlled nanoparticle synthesis via opposite-polarity electrospray pyrolysis," J. Aerosol Sci. **113** (2017) 201–211.
- F. Carbone, K. Gleason, and A. Gomez, "Probing gas-to-particle transition in a moderately sooting atmospheric pressure ethylene/air laminar premixed flame. Part I: Gas phase and soot ensemble characterization," Combust. Flame **181** (2017) 315–328.
- F. Carbone, S. Moslih, and A. Gomez, "Probing gas-to-particle transition in a moderately sooting atmospheric pressure ethylene/air laminar premixed flame. Part II: Molecular clusters and nascent soot particle size distributions," Combust. Flame **181** (2017) 329–341.
- J. Tang, W. Liu, H. Wang, and A. Gomez, "High performance metal oxide–graphene hybrid nanomaterials synthesized via opposite-polarity electrosprays," Advanced Materials **28** (2016) 10298–10303.
- B. Coriton, J.H. Frank, and A. Gomez, "Interaction of turbulent premixed flames with combustion products: Role of stoichiometry," Combust. Flame **170** (2016) 37–52.
- F. Carbone, E.L. Carlson, D. Baroni, and A. Gomez, "The whirl cookstove: A novel development for clean biomass burning," Combust. Sci. Technol. **188** (2016) 594–610.
- B. Almería and A. Gomez, "Electrospray synthesis of monodisperse polymer particles in a broad (50nm–2um) diameter range: Constraints, guiding principles and recipes," J. Colloid Interface Sci. **417** (2014) 121–130.
- L. Figura and A. Gomez, "Structure of incipiently sooting ethylene-nitrogen counterflow diffusion flames at high pressures," Combust. Flame **161** (2014) 1587–1603 (2014).
- G. Lenguito, J. Fernandez de la Mora, and A. Gomez, "Scaling up the performance of an electrospray microthruster," J. Micromech. Microeng. **24** (2014) 055003.

10. Professional development activities:

Professor Gomez is engaged in typical professional activities, all of which contribute to his professional growth. They include: attendance at International Combustion Symposia, attendance at AAAR National Meetings, and invitation to national meetings; seminars in academic institutions and government laboratories; and consulting.

1. Name and academic rank: Rebecca Kramer-Bottiglio
John J. Lee Assistant Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Engineering Science, Harvard University, 2012
M.S. Mechanical Engineering, University of California, Berkeley, 2008
B.S. Mechanical Engineering, Johns Hopkins University, 2007

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- John J. Lee Assistant Professor, 2018–present
- Assistant Professor, 2017–2018
- Assistant Professor, Mechanical Engineering, Purdue University, 2013–2017

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Materials Research Society (MRS), Institute of Electrical and Electronics Engineers (IEEE)

7. Honors and awards:
- Yale Arthur Greer Memorial Prize, 2019
- Presidential Early Career Award for Scientists and Engineers (PECASE), 2019
- Best poster award, IEEE International Conference on Soft Robotics, 2019
- Best paper award, IEEE International Conference on Soft Robotics, 2018
- Participant in NAE's Frontiers in Engineering Symposium, 2018
- ONR Young Investigator Award, 2017
- AFOSR Young Investigator Award, 2016
- NSF CAREER Award, 2015
- Forbes "30 Under 30" List, 2015
- NASA Early Career Faculty (ECF) Award, 2014
- NSF Graduate Research Fellowship, 2007
- Tau Beta Pi Engineering Honor Society
- Pi Tau Sigma Mechanical Engineering Honor Society

8. Service activities (within and outside Yale):
Outside Yale:
- Associate editor:
  - Soft Robotics (Mary Ann Liebert, Inc.)
  - Multifunctional Materials (IOP)
  - Frontiers in Robotics and AI: Soft Robotics

    - IEEE Robotics and Automation Letters
- IEEE International Conference on Soft Robotics: General Chair, 2020; Program Co-Chair, 2019; Workshop Chair, 2018
- Session/symposium/workshop organizer:
    - Continuum, Compliant, and Configurable Soft Robotics (workshop organizer), 2019
    - Materials for Next-Generation Robotics (symposium organizer), Fall MRS, 2018
    - Material Robotics: Bridging Materials Science & Robotics (workshop organizer), RSS, 2017
    - A Soft Future: From Electronic Skin to Robotics and Energy Harvesting (symposium organizer), Spring MRS, 2017
    - Materials and Manufacturing of Bio-Interface Devices and Stretchable Electronics (symposium organizer), Fall MRS, 2016
    - Soft Robotics (session organizer), SPIE DSS, 2016
    - Advanced Manufacturing of Kinetic Material Systems (session organizer), ASME MSEC, 2016
    - Material Processing of Flexible Electronic Devices and Sensors (session organizer), ASME IMECE, 2014, 2015
- Invited speaker at MRS symposium: “The Future of Materials Science Academia: Preparing for a Career in Higher Education,” 2018
- Invited successful CAREER awardee speaker at NSF CMMI CAREER Proposal Writing Workshop, 2018
- Proposal reviewer for the National Science Foundation, 2013–present
- Panelist: “Academic Interviewing at Large Research Universities,” Harvard Univ., 2013

9. Most important publications and/or presentations (last five years):
    - S.Y. Kim, Y. Choo, R.A. Bilodeau, M.C. Yuen, G. Kaufman, D.S. Shah, C.O. Osuji, and R. Kramer-Bottiglio, “Sustainable manufacturing of sensors onto soft systems using self-coagulating conductive Pickering emulsions,” Science Robotics **5** (2020) eaay3604.
    - T.L. Buckner, M.C. Yuen, SY. Kim, and R. Kramer-Bottiglio, “Enhanced variable stiffness and variable stretchability enabled by phase-changing particulate additives,” Advanced Functional Materials **29** (2019) 1903368.
    - S.Y. Kim, R. Baines, J. Booth, N. Vasios, K. Bertoldi, and R. Kramer-Bottiglio, “Reconfigurable soft body trajectories using unidirectionally stretchable composite laminae,” Nature Communications **10** (2019) 3464.
    - J. Booth, D. Shah, J. Case, E. White, M. Yuen, O. Cyr-Choiniere, and R. Kramer-Bottiglio, “OmniSkins: Robotic skins that turn soft objects into multi-functional robots,” Science Robotics **3** (2018) eaat1853.
    - J.W. Boley, E.L. White, and R.K. Kramer, “Mechanically sintered gallium–indium nanoparticles,” Advanced Materials **27** (2015) 2355–2360.

10. Professional development activities:
    - IEEE Distinguished Lecturer, 2019–present
    - Advisory board member of Advanced Intelligent Materials (Wiley)
    - Technical committee member, IEEE RAS Robotic Hand Grasping and Manipulation
    - Technical committee member, IEEE RAS Soft Robotics

1. Name and academic rank: Marshall B. Long
 Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
 Ph.D. Applied Physics, Yale University, 1980
 B.A. Physics, University of Montana, 1976

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
 - Professor, 1990–present
 - Associate Professor, 1984–1990
 - Assistant Professor, 1980–1984

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the Combustion Institute, Fellow of the Optical Society of America, Connecticut Academy of Science and Engineering

7. Honors and awards:
 - Distinguished Paper (Diagnostics), 34th International Combustion Symposium, 2013
 - Silver Medal, The Combustion Institute, 1994
 - Lilly Endowment Teaching Fellow, 1986
 - Young Alumni Award, University of Montana, 1985
 - Presidential Young Investigator Award, 1984
 - Northeast Association of Graduate Schools Book Award, 1981
 - Harding Bliss Graduate Prize, Yale University, 1980

8. Service activities (within and outside Yale):
 Within Yale:
 - Director of Undergraduate Studies for Mechanical Engineering, 2006–2011
 - Chair of Mechanical Engineering, 2000–2006
 - Director of Graduate Studies for Engineering & Applied Science, 1993–1998

 Outside Yale:
 - Editorial Board Member, Combustion Theory & Modelling, 2017–2019
 - Editorial Board Member, Proceedings of the Combustion Institute, 2010–2013
 - Chair, Gordon Research Conference on Laser Diagnostics in Combustion, 1997

9. Most important publications and/or presentations (last five years):
 - N.J. Kempema and M.B. Long, "Effect of soot self-absorption on color-ratio pyrometry in laminar coflow diffusion flames," Optics Letters **43** (2018) 1103–1106.

- S. Cao, B. Ma, D. Giassi, B.A.V. Bennett, M.B. Long and M.D. Smooke, "Effects of pressure and fuel dilution on coflow laminar methane-air diffusion flames: A computational and experimental study," Combust. Theory Model. **22** (2018) 316–337.
- N.J. Kempema, B. Ma, and M.B. Long, "Investigation of in-flame soot optical properties in laminar coflow diffusion flames using thermophoretic particle sampling and spectral light extinction," Applied Physics B **122** (2016) 232.
- D. Giassi and M.B. Long, "Signal-to-noise ratio improvements in laser flow diagnostics using time-resolved image averaging and high dynamic range imaging," Experiments in Fluids **57** (2016) 135.
- N.J. Kempema and M.B. Long, "Boundary condition thermometry using a thermographic-phosphor-coated thin filament," Appl. Optics **55** (2016) 4691–4698.
- D. Giassi, S. Cao, B.A.V. Bennett, D.P. Stocker, F. Takahashi, M.D. Smooke, and M.B. Long, "Analysis of CH* concentration and flame heat release in laminar coflow diffusion flames under microgravity and normal gravity," Combust. Flame **167** (2016) 198–206.
- N.J. Kempema and M.B. Long, "Combined optical and TEM investigations for a detailed characterization of soot aggregate properties in a laminar coflow diffusion flame," Combust. Flame **164** (2016) 373–385.
- D. Giassi, B. Liu, and M.B. Long, "Use of high dynamic range imaging for quantitative combustion diagnostics," Appl. Optics **54** (2015) 4580–4588.
- B. Ma, S. Cao, D. Giassi, D.P. Stocker, F. Takahashi, B.A.V. Bennett, M.D. Smooke, and M.B. Long, "An experimental and computational study on soot formation in a coflow jet flame under microgravity and normal gravity," Proc. Combust. Inst., **35** (2015) 839–846.
- S. Cao, B. Ma, B.A.V. Bennett, D. Giassi, D.P. Stocker, F. Takahashi, M.B. Long, and M.D. Smooke, "A computational and experimental study of coflow laminar methane/air diffusion flames: Effects of fuel dilution, inlet velocity, and gravity," Proc. Combust. Inst., **35** (2015) 897–903.

10. Professional development activities:
    - Referee for numerous journals including Combustion & Flame, Applied Optics, Experiments in Fluids, and Proceedings of the Combustion Institute
    - Proposal reviewer for DOE, NSF, and AFOSR

1. Name and academic rank: Corey S. O'Hern
Professor of Mechanical Engineering & Materials Science, Applied Physics, and Physics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Physics, University of Pennsylvania, 1999
B.S. Physics, Duke University, 1994

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Professor, MEMS, Applied Physics, and Physics, 2018–present
- Associate Professor, MEMS, Applied Physics, and Physics, 2011–2018
- Associate Professor, MEMS and Physics, 2006–2011
- Assistant Professor, MEMS and Physics, 2002–2006
- Postdoctoral Associate, Chemistry & Biochemistry, UCLA, 1999–2002
- Postdoctoral Associate, Physics, University of Chicago, 1999–2002

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Physical Society (APS); American Chemical Society (ACS); Biophysical Society (BPS)

7. Honors and awards:
- Yale School of Eng. & Applied Science Ackerman Teaching and Mentoring Award, 2018
- APS Outstanding Referee, 2015
- NSF Cyber-Enabled Discovery and Innovation Award, 2008
- NSF CAREER Award, 2005
- Summa cum laude and Phi Beta Kappa, Duke University, 1994

8. Service activities (within and outside Yale):
Within Yale:
- Director of Graduate Admissions, Computational Biol. & Bioinformatics, 2012–present
- Director of Undergraduate Studies for Mechanical Engineering, 2011–present
- Co-founder and member of Executive Committee for Yale's Integrated Graduate Program in Physical and Engineering Biology, 2008–present

Outside Yale:
- Workshop organizer, 4th International Conf. on Packing Problems, New Haven, CT, 2019
- Co-organizer, Minisymposium, "Physics of dense granular media," 10th EUROMECH Solid Mechanics Conference, Bologna, Italy, 2018
- Co-organizer, 16th Annual Northeastern Granular Materials Workshop, Yale Univ., 2018

- International evaluation of School of Physics, Huazhong University of Science and Technology, Wuhan, China, 2018
- Scientific coordinator for KITP program: Avalanches, intermittency, and nonlinear response in far-from-equilibrium solids, 2014

9. Most important publications and/or presentations (last five years):
   - Y.-C. Hu, J. Schroers, M.D. Shattuck, and C.S. O'Hern, "Tuning the glass-forming ability of metallic glasses through energetic frustration," Phys. Rev. Materials **3** (2019) 085602.
   - A. Boromand, A. Signoriello, J. Lowensohn, C.S. Orellana, E.R. Weeks, F. Ye, M.D. Shattuck, and C.S. O'Hern, "The role of deformability in determining the structural and mechanical properties of jammed packings of bubbles and emulsions," Soft Matter **15** (2019) 5854–5865.
   - Q. Wu, C. Cui, T. Bertrand, M.D. Shattuck, and C.S. O'Hern, "Active acoustic switches using 2D granular crystals," Phys. Rev. E **99** (2019) 062901.
   - D. Das, D. Jülich, J. Schwendinger-Schreck, E. Guillon, A. Lawton, N. Dray, T. Emonet, C.S. O'Hern, M.D. Shattuck, and S.A. Holley, "Organization of embryonic morphogenesis via mechanical information," Developmental Cell **49** (2019) 829.
   - J.D. Treado, Z. Mei, L. Regan, and C.S. O'Hern, "Void distributions reveal structural link between jammed packings and protein cores," Phys. Rev. E **99** (2019) 022416.
   - M. Fan, A. Nawano, J. Schroers, M.D. Shattuck, and C.S. O'Hern, "Intrinsic dissipation in metallic glass resonators," J. Chem. Phys. **151** (2019) 144506.
   - F. Xiong, P. Wang, A.H. Clark, T. Bertrand, N.T. Ouellette, M.D. Shattuck, and C.S. O'Hern, "Comparison of shear and compression jammed packings of frictional disks," Granular Matter **21** (2019) 109.
   - Y. Yuan, K. VanderWerf, M.D. Shattuck, and C.S. O'Hern, "Jammed packings of 3D superellipsoids with tunable packing fraction, contact number, and ordering," Soft Matter **15** (2019) 9751.
   - A. Bormand, A. Signoriello, F. Ye, C.S. O'Hern, and M.D. Shattuck, "Jamming of deformable polygons," Phys. Rev. Lett. **121** (2018) 248003.
   - S. Chen, T. Bertrand, W. Jin, C.S. O'Hern, and M.D. Shattuck, "Stress anisotropy in shear-jammed packings of frictionless disks," Phys. Rev. E **98** (2018) 042906.
   - C. Oi, J.D. Treado, Z.A. Levine, C.S. Lim, K.M. Knecht, Y. Xiong, C.S. O'Hern, and L. Regan, "A Thr zipper that mediates protein-protein interactions: Structure and prediction," Protein Science **27** (2018) 1969.
   - A.H. Clark, M.D. Shattuck, N.T. Ouellette, and C.S. O'Hern, "Critical scaling of the yielding transition in sheared granular media," Phys. Rev. E **97** (2018) 062901.

10. Professional development activities:
    - Reviewer for Nature, Science, Proc. Natl. Acad. Sci. U.S.A., Physical Review
    - Panelist for National Science Foundation programs:
      - Particulate & Multiphase Proc., Division of Chem., Bioeng., Envir., & Transp. Syst.
      - Physics of Living Systems, Division of Physics
      - Chemistry of Life Processes, Division of Chemistry
    - Public lecture, Yale Young Global Scholars Program, "The mysteries of sand," 2019
    - Public lecture, Hartford Audubon Society, "The strength of bird nests," 2018

1. Name and academic rank: Diana Qiu
Assistant Professor of Mechanical Engineering and Materials Science

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Physics, University of California, Berkeley, 2017
   - M.A. Physics, University of California, Berkeley 2014
   - B.S. Physics, Yale University, 2011

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Assistant Professor, 2020–present
   - Postdoctoral Researcher, Lawrence Berkeley National Lab, 2017–2019

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Physical Society (APS)

7. Honors and awards:
   - Jackson C. Koo Award in condensed matter physics, UC Berkeley, 2017
   - National Science Foundation Graduate Research Fellowship, 2011
   - Berkeley Chancellor's Fellowship 2011

8. Service activities (within and outside Yale):
   Outside Yale:
   - Instructor at annual BerkeleyGW Workshop, Lawrence Berkeley Natl. Lab, 2013–present
   - Mentor for the Berkeley Compass Project at UC Berkeley, 2013–2015
   - Developer of the open source BerkeleyGW code, 2012–present
   - Mentor for Society of Women in the Physical Sciences at UC Berkeley, 2011–2016

9. Most important publications and/or presentations (last five years):
   - S. Barja, S. Refaely-Abramson, B. Schuler, D.Y. Qiu, A. Pulkin, S. Wickenburg, H. Ryu, M.M. Ugeda, C. Kastl, C. Chen, C. Hwang, A. Schwartzberg, S. Aloni, S.-K. Mo, D.F. Ogletree, M.F. Crommie, O. Yazyev, S.G. Louie, J.B. Neaton, and A. Weber-Bargioni, "Chalcogen vacancies, substituted chalcogens and mid-gap states in 2D-transition metal dichalcoginides," Nature Communications (2019) in press.
   - B. Schuler, D. Y. Qiu, S. Refaely-Abramson, C. Kastl, C.T. Chen, S. Barja, R.J. Koch, D.F. Ogletree, S. Aloni, A.M. Schwartzberg, S. G. Louie, J.B. Neaton, and A. Weber-Bargioni, "Measuring the giant spin-orbit splitting of deep in-gap defect states of engineered sulfur vacancies in monolayer WS_2," Physical Review Letters (2019) in press.

- S. Refaely-Abramson, D.Y. Qiu, S.G. Louie, and J.B. Neaton, “Defect-induced modification of low-lying excitons and valley selectivity in monolayer transition metal dichalcogenides,” Physical Review Letters **121** (2018) 167402.
- D.Y. Qiu, F.H. da Jornada, and S.G. Louie, “Environmental screening effects in 2D materials: Renormalization of the bandgap, electronic structure, and optical spectra of few-layer black-phosphorus,” Nano Letters **17** (2017) 4706–4712.
- F. H. da Jornada, D. Y. Qiu, and S. G. Louie, “Non-uniform sampling schemes of the Brillouin zone for many-electron perturbation-theory calculations in reduced dimensionality,” Physical Review B **95** (2017) 035109.
- L. Li, J. Kim, C. Jin, G. Ye, D.Y. Qiu, F.H. da Jornada, Z. Shi, L. Chen, Z. Zhang, F. Yang, K. Watanabe, T. Taniguchi, W. Ren, S.G. Louie, X. Chen, Y. Zhang, and F. Wang, “Direct observation of layer-dependent electronic structure in phosphorene,” Nature Nanotechnology **12** (2017) 21–25.
- D.Y. Qiu, F.H. da Jornada, and S.G. Louie, “Screening and many-body effects in two-dimensional crystals: Monolayer MoS_2,” Physical Review B **93** (2016) 235435.
- D.Y. Qiu, T. Cao, and S.G. Louie, “Nonanalyticity, valley quantum phases, and lightlike exciton dispersion in monolayer transition metal dichalcogenides: Theory and first-principles calculations,” Physical Review Letters **115** (2015) 176801.
- A.J. Bradley, M.M. Ugeda, F.H. da Jornada, D.Y. Qiu, W. Ruan, W. Zhang, S. Wickenburg, A. Riss, J. Lu, S.-K. Mo, Z. Hussain, Z.-X. Shen, S.G. Louie, and M.F. Crommie, “Probing the role of interlayer coupling and coulomb interactions on electronic structure in few-layer $MoSe_2$ nanostructures,” Nano Letters **15** (2015) 2594–2599.

10. Professional development activities:
    - Representative for Department of Energy (DOE) Basic Energy Sciences (BES) Early Career Network (ECN), 2017–present
    - Session Chair at APS March Meeting, 2017

1. Name and academic rank: Jan Schroers
Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Physics, RWTH Aachen, Germany, 1997
   - M.S. Physics, University of Cologne, Germany, 1994
   - B.S. Physics, University of Cologne, Germany, 1992

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Professor, 2012–present
   - Visiting Professor, Mechanical Eng., Massachusetts Institute of Technology, 2016–2017
   - Visiting Professor, EPFL, Lausanne, Switzerland, 2013–2014
   - Associate Professor, 2006–2012
   - Research Fellow, Materials Science, California Institute of Technology, 1998–2002

4. Non-academic experience:
   - Scientific Advisor, Desktop Metals, 2016–present
   - Chief Scientific Advisor, Supercool Metals, 2013–present
   - Director of Research, Liquidmetal Technologies, 2002–2006

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Materials Research Society (MRS), The Minerals, Metals, & Materials Society (TMS)

7. Honors and awards:
   - LiXun Award, Chinese Academy of Science, Shenyang, 2017
   - Hauptvortrag, German Physical Society, 2012

8. Service activities (within and outside Yale):
   Within Yale:
   - Director of Graduate Studies, Mechanical Engineering & Materials Science, 2012–present

   Outside Yale:
   - Session chair at bulk metallic glass (BMG) conferences (e.g., MRS fall meeting, TMS, BMG, RQ, THERMEC)

9. Most important publications and/or presentations (last five years):
   - Z. Liu, S. Sohn, N. Liu, and J. Schroers, “Nanomolding with crystalline metals: The smaller the easier,” Physical Review Letters **122** (2019) 036101.
   - S. Kube, S. Sohn, D. Uhl, A. Datye, A. Mehta, and J. Schroers, “Phase selection motifs in high entropy alloys revealed through combinatorial methods: Large atomic size difference favors BCC over FCC,” Acta Materialia **166** (2019) 677–686.

- M. Gibson, J.S. Myerberg, R. Fulop, M.D. Verminski, E.M. Sachs, Y.M. Chiang, C.A. Schuh, A.J. Hart, and J. Schroers, "3D printing metals like thermoplastics: Fused filament fabrication of metallic glasses," Materials Today **21** (2018) 697–702.
- J. Ketkaew, W. Chen, H. Wang, A. Datye, M. Fan, G. Pereira, U.D. Schwarz, Z. Liu, R. Yamada, W. Dmowski, M.D. Shattuck, C.S. O'Hern, T. Egami, E. Bouchbinder, and J. Schroers, "Mechanical glass transition revealed by the fracture toughness of metallic glasses," Nature Communications **9** (2018) 3271.
- S. Ding, Y. Liu, S. Sohn, F. Walker, and J. Schroers, "Combinatorial development of metallic glasses," Nature Materials **13** (2014) 494–500.

10. Professional development activities:
    - Reviewer for Nature, Nature Communications, Physical Review Letters, Acta Materialia, and Scripta Materialia
    - Symposium organizer:
      - Bulk Metallic Glass Symposium, MRS Fall Meeting, Boston, 2013 and 2007
      - Processing of Bulk Metallic Glass Symposium, THERMEC, Quebec, 2011

1. Name and academic rank: Udo D. Schwarz
Professor of Mechanical Engineering & Materials Science;
Professor of Chemical & Environmental Engineering

2. Degrees with disciplines, institutions, and dates:
Ph.D. Physics, University of Basel, Switzerland, 1993
Diploma Physics, University of Basel, Switzerland, 1989

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Professor, Chemical & Environmental Engineering, Yale University, 2010–present
   - Professor, 2009–present
   - Associate Professor, 2002–2009
   - Visiting Senior Scientist, Materials Science Division, Lawrence Berkeley National Laboratory, University of California, Berkeley, 2001–2002
   - Lecturer/Group Leader, Inst. of Appl. Physics, Univ. of Hamburg, Germany, 1999–2001
   - Staff Scientist, Institute of Applied Physics, University of Hamburg, Germany, 1993–1999
   - Postdoctoral Associate, Institute of Applied Physics, Univ. of Hamburg, Germany, 1993

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Physical Soc. (APS), American Vacuum Soc. (AVS), American Chemical Soc. (ACS), Materials Research Soc. (MRS)

7. Honors and awards:
   - Heisenberg Fellowship from the German Research Society, 2000–2002
   - Gaede Award (Principal Prize of the German Vacuum Society), 1999
   - German “Habilitation,” 1999
   - Venia Legendi (“Privatdozent”), 1999

8. Service activities (within and outside Yale):
Within Yale:
   - Chair, Yale Science and Engineering Chairs Council, 2018–2019
   - Member of the Energy Science Institute Advisory Committee, 2013–present
   - Chair, Mechanical Engineering & Materials Science, 2012–present
   - Director of Graduate Studies, Mechanical Engineering & Materials Science, 2009–2012
   - Frequent member of a variety of internal committees (search committees, etc.)

Outside Yale:
   - Editorships:
     - Beilstein J. Nanotechnol., Assoc. Editor, 2010–2018, and Advis. Editor, 2018–present
     - Editor, special issues such as Appl. Phys. A, 2001; Nanotechnology, 2005 and 2009; J.

Vac. Sci. Technol., 2010; Beilstein J. Nanotechnol., 2012, 2013, 2014, 2016, and 2017

- Conference/session/symposium/workshop organizer:
  - 14th Nanosci. and Nanotechnol. Conf. (international advisory board), 2018
  - Frontiers in Scanning Probe Microscopy (symposium co-organizer), Fall MRS, 2015
  - Materials Solutions for High Demanding Tribological Applications (internat'l advis. board), 13th Internat'l Ceramics Congress and 6th Forum on New Materials, 2014
  - International Conference on Nanoscience and Technology (program committee), 2014
  - AVS 60th Int. Symp. and Exhib., Nano-Scale Sci. and Tech. Div. (progr. chair), 2013
  - 12th Conf. on Noncontact Atomic Force Microscopy (conf. chair and organizer), 2009
  - Noncontact Atomic Force Microscopy (NC-AFM) Conference Series (steering committee member), 2003–present
- Nanometer-Scale Science and Technology Division of the American Vacuum Society: Board member, 2008-2010; Chair-elect, 2010-2011; Chair, 2011-2012

9. Most important publications and/or presentations (last five years):
   - A. Datye, S.A. Kube, D. Verma, J. Schroers, and U.D. Schwarz, "Accelerated discovery and mechanical property characterization of amorphous alloys in the Mg-Zn-Ca and the Fe-Mg-Zn systems using high-throughput methods," J. Mater. Chem. B **7** (2019) 5392–5400.
   - R. Li, Z. Chen, A. Datye, G.H. Simon, J. Ketkaew, E. Kinser, Z. Liu, C. Zhou, O.E. Dagdeviren, S. Sohn, J.P. Singer, C.O. Osuji, J. Schroers, and U.D. Schwarz, "Atomic imprinting into metallic glasses," Communications Physics **1** (2018) 75.
   - J. Ketkaew, W. Chen, H. Wang, A. Datye, M. Fan, G. Pereira, U.D. Schwarz, Z. Liu, R. Yamada, W. Dmowski, M.D. Shattuck, C.S. O'Hern, T. Egami, E. Bouchbinder, and J. Schroers, "Mechanical glass transition revealed by the fracture toughness of metallic glasses," Nature Communications **9** (2018) 3271.
   - A.M. Loye, E.R. Kinser, S. Bensouda, M. Shayan, R. Davis, R. Wang, Z. Chen, U.D. Schwarz, J. Schroers, and T.R. Kyriakides, "Regulation of mesenchymal stem cell differentiation by nanopatterning of bulk metallic glass," Scientific Reports **8** (2018) 8758.
   - O.E. Dagdeviren, C. Zhou, E.I. Altman, and U.D. Schwarz, "Quantifying tip-sample interactions in vacuum using cantilever-based sensors: An analysis," Physical Review Applied **9** (2018) 044040.
   - J.-H. Jhang, C. Zhou, O.E. Dagdeviren, G.S. Hutchings, U. D. Schwarz, and E.I. Altman, "Growth of two-dimensional silica and aluminosilicate bilayers on Pd(111): From incommensurate to commensurate crystalline," Phys. Chem. Chem. Phys. **19** (2017) 14001–14011.
   - O.E. Dagdeviren, C.Zhou, K. Zou, G.H. Simon, S.D. Albright, S. Mandal, M.D. Morales-Acosta, X. Zhu, S. Ismail-Beigi, F.J. Walker, C.H. Ahn, U.D. Schwarz, and E.I. Altman, "Length scale and dimensionality of defects in epitaxial SnTe topological crystalline insulator films," Advanced Materials Interfaces **4** (2017) 1601011.

10. Professional development activities:
    - Frequent reviewer for Science, Nature, Advanced Materials, Small, Nano Letters, ACS Nano, Physical Review Letters, etc.
    - Grant reviewer for NSF, DOE, DoD, and a whole set of international science foundations (Germany, Austria, Switzerland, the Netherlands, etc.)

1. Name and academic rank: Mitchell D. Smooke
Strathcona Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   - M.B.A. Management and Finance, University of California, Berkeley, 1983
   - Ph.D. Applied Mathematics, Harvard University, 1979
   - M.S. Applied Mathematics, Harvard University, 1974
   - B.S. Physics, Rensselaer Polytechnic Institute, 1973

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Interim Dean, School of Engineering & Applied Science, Yale University, 2018–2019
   - Acting Dean, School of Engineering & Applied Science, Yale University, 2000
   - Strathcona Professor, 1995–present
   - Professor, 1993–1995
   - Associate Professor, 1986–1993
   - Assistant Professor, 1984–1986

4. Non-academic experience:
   - Staff Scientist, Sandia National Laboratories, Livermore, California, 1978–1984

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the Combustion Institute; Fellow of American Institute of Aeronautics and Astronautics (AIAA); Fellow of Society of Industrial and Applied Mathematics (SIAM); Fellow of Institute of Physics (IOP); Connecticut Academy of Science and Engineering; American Society of Mechanical Engineers (ASME)

7. Honors and awards:
   - AIAA Propellant and Combustion Award, AIAA, 2015
   - The Combustion Institute Zeldovich Gold Medal, 2012
   - DoD SERDP WSP Project of the Year Award, 2011
   - Yale Graduate School Mentor Award, 2008
   - Yale College Dylan Hixon Prize for Teaching Excellence in the Natural Sciences, 2006
   - Yale Science & Eng. Alumni Award for Advancement of Basic and Appl. Research, 2005
   - Yale Engineering Sheffield Teaching Award, 2004
   - Oppenheim Prize, Institute for the Dynamics of Explosions and Reacting Systems, 2004
   - The Combustion Institute Silver Medal, 1994
   - Technical Achievement Award, Sandia National Laboratories, 1982

8. Service activities (within and outside Yale):

Within Yale:

- Director of Graduate Studies for Engineering & Applied Science, 2002–2003
- Chair of Mechanical Engineering, 1994–2000, 2006–2012
- Director of Undergraduate Studies for Mechanical Engineering, 1985–1994, 2000–2006

Outside Yale:

- Co-organizer of seven SIAM Int'l Conferences on Numerical Combustion, 1991–2017
- Member, Combustion Research Facility Advisory Board, Sandia National Laboratories, Livermore, California, 2013–2017
- Board of Directors, The Combustion Institute, 2006–2018
- Member, Mechanical Eng. External Advisory Board, Univ. of Connecticut, 2006–present
- Member, Engineering Advisory Board, Fairfield University, 2005–2015
- Elected officer of the Eastern States Section of the Combustion Institute: Chair, 2003–2005; Vice-Chair, 2001–2003; Program Chair, 1996–1997; Papers Chair, 1994–1995
- Editor, Theoretical and Computational Fluid Dynamics, 2001–2005
- Co-Editor-In-Chief, Combustion Theory and Modelling, 1996–present

9. Most important publications and/or presentations (last five years):

- G. Derk, E. Boyer, G.A. Risha, R.A. Yetter, R.R. Dobbins, and M. D. Smooke, "The effect of tube diameter on the burning rate of nitromethane as a function of pressure," Joint Mtg of 49th Combust. Subcomm. and 66th JANNAF Prop. Mtg, Dayton, OH, 2019.
- S. Cao, B. Ma, D. Giassi, B.A.V. Bennett, M.B. Long and M.D. Smooke, "Effects of pressure and fuel dilution on coflow laminar methane-air diffusion flames: A computational and experimental study," Combust. Theory Model. **22** (2018) 316–337.
- D. Giassi, S. Cao, B.A.V. Bennett, D.P. Stocker, F. Takahashi, M.D. Smooke, and M.B. Long, "Analysis of CH* concentration and flame heat release in laminar coflow diffusion flames under microgravity and normal gravity," Combust. Flame **167** (2016) 198–206.
- S. Cao, B.A.V. Bennett, and M.D. Smooke, "MC-Smooth: A mass-conserving, smooth vorticity-velocity formulation for multi-dimensional flows," Combust. Theory Model. **19** (2016) 657–695.
- R.R. Dobbins, R.J. Hall, S. Cao, B.A.V. Bennett, M.B. Colket, and M.D. Smooke, "Radiative emission and reabsorption in laminar, ethylene-fueled diffusion flames using the discrete ordinates method," Combust. Sci. Technol. **187** (2015) 230–248.
- B. Ma, S. Cao, D. Giassi, D.P. Stocker, F. Takahashi, B.A.V. Bennett, M.D. Smooke, and M.B. Long, "An experimental and computational study on soot formation in a coflow jet flame under microgravity and normal gravity," Proc. Combust. Inst., **35** (2015) 839–846.
- S. Cao, B. Ma, B.A.V. Bennett, D. Giassi, D.P. Stocker, F. Takahashi, M.B. Long, and M.D. Smooke, "A computational and experimental study of coflow laminar methane/air diffusion flames: Effects of fuel dilution, inlet velocity, and gravity," Proc. Combust. Inst., **35** (2015) 897–903.

10. Professional development activities:

- Chair, National Academies Committee, Cyberinfrastructure for Combustion, 2009–2011
- Program Co-Chair, 32^{nd} International Combustion Symposium, 2008
- Propellant and Combustion Technical Program Chair, ASM AIAA, Reno, NV, 2005
- Propellant and Combustion Technical Committee, AIAA, 2001–2010

1. Name and academic rank: Madhusudhan Venkadesan
Assistant Professor of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mechanical & Aerospace Engineering, Cornell University, 2007
M.S. Mechanical & Aerospace Engineering, Cornell University, 2003
B.Tech. Mechanical Engineering, Indian Institute of Technology, Madras, India, 2000

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Assistant Professor, 2015–present
- Reader, National Centre for Biological Sciences – Tata Institute of Fundamental Research, Bangalore, 2011–2014
- Postdoctoral Fellow, Harvard University, Applied Mathematics and Human Evolutionary Biology, 2008–2010
- Postdoctoral Associate, Mathematics, Cornell University, 2007–2008

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Society of Biomechanics (ASB), Society for the Neural Control of Movement (NCM), Society for Integrative and Comparative Biology (SICB), American Physical Society (APS), Institute of Electrical and Electronics Engineers (IEEE)

7. Honors and awards:
- Poorvu Family Award for Excellence in Interdisciplinary Teaching, Yale University, 2018
- Sackler Institute Seed Grant Award, Yale University, 2017
- Junior Faculty Fellowship, Yale University, 2017
- Young Investigator Award, Human Frontier Science Program, 2013
- Intermediate Fellowship Award, Wellcome Trust – DBT India Alliance, 2011
- Scholarship Award, Society for the Neural Control of Movement, 2010
- Journal of Biomechanics Award, 2006
- Exceptional Teaching Assistant Award, Cornell University, 2004
- Sage Fellowship Award, Cornell University, 2000
- Engineering Supplementary Fellowship Award, Cornell University, 2000

8. Service activities (within and outside Yale):
Within Yale:
- Course of Study Committee, 2019–present
- Departmental seminar committee, MEMS, 2018

- Dean Search Committee, School of Engineering & Applied Science, 2017
- Fulbright committee, de facto member, 2015–2016
- Graduate Student Admission Committee, MEMS, 2015–2016

Outside Yale:

- Secretary General, Comparative Neuromuscular Biomechanics, Working Group of the International Society of Biomechanics, 2019–present
- Associate Editor, Royal Society Open Science, 2018–present
- Associate Editor, International Conference on Rehabilitation Robotics, 2015, 2017

9. Most important publications and/or presentations (last five years):
   - M. Venkadesan, A. Yawar, C.M. Eng, M.A. Dias, D.K. Singh, S. Tommasini, A. Haims, M.M. Bandi, and S. Mandre, "Stiffness of the human foot and evolution of the transverse arch," Nature **579** (2020) 97–100.
   - N. Dhawale, S. Mandre, and M. Venkadesan, "Dynamics and stability of running on rough terrains," Royal Society Open Science **6** (2019) 181729.
   - K.D. Nguyen, N. Sharma, and M. Venkadesan, "Active viscoelasticity of sarcomeres," Frontiers in Robotics and AI **5** (2018) 69.
   - K. Nguyen, N. Yu, M.M. Bandi, M. Venkadesan, and S. Mandre, "Curvature-induced stiffening of a fish fin," Journal of The Royal Society Interface **14** (2017) 20170247.
   - M. Venkadesan and L. Mahadevan, "Optimal strategies for throwing accurately," Royal Society Open Science **4** (2017) 170136.

10. Professional development activities:
    - Frontiers of Science and Technology: Yale Young Global Scholars public lecture on the physics behind human evolution, New Haven, CT, 2019
    - Sensitive Machine: Workshop and Panel, Yale School of Art, New Haven, CT, 2018, 2019
    - Collaborative experimental design and analytics (CEDA): Walking fish, Team Leader, Okinawa, Japan, 2018
    - Sawaal Jawaab. Public lecture and discussion, on biomechanics and human evolution, Hyderabad, India, 2014
    - Chai & Why? Public lecture and discussion on biomechanics and human evolution, Mumbai, India, 2014
    - Physics of Life: Summer school on Engineering and Applied Mathematical methods in Biology, Bangalore, India, 2013
    - Hackteria 2013: Session on mechanical "hacking" for artists, design and science undergraduates, Bangalore, India, 2013
    - Sympotein IX: Bioinspired designs – team advisor, Bangalore, India, 2011
    - INSPIRE Science Camp: Five-day science camp for high school students in Kannur, India, 2011

1. Name and academic rank: Beth Anne V. Bennett
Lecturer of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Mechanical Engineering, Yale University, 1997
M.Phil.	Mechanical Engineering, Yale University, 1994
M.S.	Mechanical Engineering, Yale University, 1992
B.S.	Mechanical Engineering & Applied Mathematics, Yale University, 1991

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Lecturer, 2015–present
   - Lecturer and Senior Research Scientist, 2010–2015
   - Lecturer and Research Scientist, 2005–2010
   - Lecturer and Associate Research Scientist, 1999–2005
   - Lecturer and Postdoctoral Research Associate, 1997–1999

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Society of Mechanical Engineers (ASME), Society for Industrial and Applied Mathematics (SIAM), American Society for Engineering Education (ASEE)

7. Honors and awards:
   - Acknowledged by Yale's Poorvu Center for Teaching and Learning for exemplary use of the Canvas Learning Management System for an undergraduate course (ENAS 441/ENAS 748/MENG 441: Applied Numerical Methods for Differential Equations), as identified via a survey of Yale undergraduates, 2018
   - Honorable mention for technical poster at 30th Annual Meeting of the American Society for Gravitational and Space Research, 2014
   - ADVANCE Fellows Award, National Science Foundation, 2002–2006
   - Harding Bliss Graduate Prize, Yale University, 1997
   - National Defense Science & Engineering Graduate (NDSEG) Fellowship, 1993–1997
   - Summa cum laude and Phi Beta Kappa, Yale University, 1991

8. Service activities (within and outside Yale):
   Within Yale:
   - First-year and sophomore faculty adviser, 2011–2017, 2019–present
   - Discussant, Engineering and Science Weekend, 2011, 2012, 2014–2018
   - Faculty adviser for undergraduate chapter of SWE, 2011–2017
   - Faculty adviser for undergraduate chapter of Tau Beta Pi, 2010–2017

- Faculty adviser for undergraduate chapter of ASME, 2010–2017
- Alumni interviewer of prospective Yale undergraduates in Engineering & Applied Science, 1999–2016

Outside Yale:

- Elected officer of the New Haven Section of ASME: History & Heritage Chair, 2017–present; Chair & Treasurer, 2007–2017; Vice Chair, 2003–2007; Treasurer, 1999–2003
- Elected officer of the Eastern States Section of the Combustion Institute: Secretary, 2011–2016; Member-at-Large, 2009–2011
- Judge for several student engineering competitions at the University of New Haven and at the University of Connecticut, 2010–2016
- Member, Mechanical Engineering Advisory Board, University of New Haven, 2009–2017
- Co-organizer, ASME Student Professional Development Conference for District A, 2012

9. Most important publications and/or presentations (last five years):
   - S. Cao, B. Ma, D. Giassi, B.A.V. Bennett, M.B. Long, and M.D. Smooke, "Effects of pressure and fuel dilution on coflow laminar methane-air diffusion flames: A computational and experimental study," Combust. Theory Model. **22** (2018) 316–337.
   - D. Giassi, S. Cao, B.A.V. Bennett, D.P. Stocker, F. Takahashi, M.D. Smooke, and M.B. Long, "Analysis of CH* concentration and flame heat release in laminar coflow diffusion flames under microgravity and normal gravity," Combust. Flame **167** (2016) 198–206.
   - S. Cao, B.A.V. Bennett, and M.D. Smooke, "MC-Smooth: A mass-conserving, smooth vorticity-velocity formulation for multi-dimensional flows," Combust. Theory Model. **19** (2016) 657–695.
   - R.R. Dobbins, R.J. Hall, S. Cao, B.A.V. Bennett, M.B. Colket, and M.D. Smooke, "Radiative emission and reabsorption in laminar, ethylene-fueled diffusion flames using the discrete ordinates method," Combust. Sci. Technol. **187** (2015) 230–248.
   - B. Ma, S. Cao, D. Giassi, D.P. Stocker, F. Takahashi, B.A.V. Bennett, M.D. Smooke, and M.B. Long, "An experimental and computational study of soot formation in a coflow jet flame under microgravity and normal gravity," Proc. Combust. Inst. **35** (2015) 839–846.
   - S. Cao, B. Ma, B.A.V. Bennett, D. Giassi, D.P. Stocker, F. Takahashi, M.B. Long, and M.D. Smooke, "A computational and experimental study of coflow laminar methane/air diffusion flames: Effects of fuel dilution, inlet velocity, and gravity," Proc. Combust. Inst. **35** (2015) 897–903.

10. Professional development activities:
    - Reviewer for over 10 journals, including Combustion & Flame, Combustion Theory and Modelling, and Journal of Computational Physics, 1999–2015
    - Chair of 15 technical sessions at international and U.S. conferences, 1998–2015

1. Name and academic rank: Joran Booth
Lecturer and Research Scientist, Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mechanical Engineering, Purdue University, 2016
B.S. Mechanical Engineering, Brigham Young University, 2010

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Lecturer and Research Scientist, 2018–present
- Postdoctoral Research Associate, 2017–2018
- Postdoctoral Research Associate, Purdue University, 2016–2017
- Graduate Lecturer, Purdue University, 2015
- Lab Coordinator and Head Teaching Assistant, Purdue University, 2011–2015

4. Non-academic experience:
- Technical Adviser, BOCE LLC, 2015–2016
- Mechanical Engineering Intern, IMMI, 2014
- Legal Intern, Booth-Udall LLC, 2010

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Society of Mechanical Engineers (ASME), Order of the Engineer

7. Honors and awards:
- 2017 Journal of Mechanical Design Editor's Choice Award, awarded in 2018
- Nominated for the Purdue Excellence in Teaching Award, 2016
- Ward A. Lambert Graduate Teaching Fellowship, 2015
- Graduate Award for Teaching Excellence (Teaching Academy of Purdue), 2015
- Estus H. and Vashti L. Magoon Award for Excellence in Teaching, 2015
- Mechanical Engineering Summer Research Grant, 2015
- ASME Parsons Scholarship, 2014
- Cecilia Zissis Scholarship, 2014
- Gerald I. Gilbert Memorial Scholarship, 2014
- Ingersoll Rand Fellowship for Academic Excellence, 2013–2014
- Estus H. and Vashti L. Magoon Award for Excellence in Teaching, 2012

8. Service activities (within and outside Yale):
Outside Yale:
- Founded a Maker club, Purdue University, 2011–2015
- Organized and presented at 14 workshops focusing on specific design skills, 2011–2015

9. Most important publications and/or presentations (last five years):

- S.Y. Kim, R. Baines, J. Booth, N. Vasios, K. Bertoldi, and R. Kramer-Bottiglio, “Reconfigurable soft body trajectories using unidirectionally stretchable composite laminae,” Nature Communications **10** (2019) 3464.
- R.L. Baines, J.W. Booth, F.E. Fish, and R. Kramer-Bottiglio, “Toward a bio-inspired variable-stiffness morphing limb for amphibious robot locomotion,” IEEE International Conference on Soft Robotics (2019) 704–710.
- J. Booth, D. Shah, J. Case, E. White, M. Yuen, O. Cyr-Choiniere, and R. Kramer-Bottiglio, “OmniSkins: Robotic skins that turn soft objects into multi-functional robots,” Science Robotics **3** (2018) eaat1853.
- J.C. Case, J. Booth, D.S. Shah, M. Yuen, and R. Kramer-Bottlglio, “State and stiffness estimation using robotic fabrics,” IEEE International Conference on Soft Robotics (2018) 522–527.
- J.W. Booth, J. Alperovich, P. Chawla, J. Ma, T.N. Reid, and K. Ramani, “The Design for Additive Manufacturing worksheet,” ASME J. Mech. Design **139** (2017) 100904.
- W.-L. Hu, J.W. Booth, and T. Reid, “The relationship between design outcomes and mental states during ideation,” ASME J. Mech. Design **139** (2017) 051101.
- J.W. Booth, E.A. Taborda, K. Ramani, and T. Reid, “Interventions for improving sketching skills and reducing inhibition for novice engineering designers,” Design Studies **43** (2016) 1–23.
- J.W. Booth, T.N. Reid, C. Eckert, and K. Ramani, “Comparing functional analysis methods for product dissection tasks,” ASME J. Mech. Design **137** (2015) 081101. Featured on the JMD Companion site.

10. Professional development activities:

- Reviewer for research publications, various journals, and conferences
- Continuing education through online courses on machine learning

1. Name and academic rank: Lawrence Wilen
Senior Research Scientist, Center for Engineering Innovation and Design (CEID), and Lecturer, Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Physics, Princeton University, 1986
B.S. Physics, University of California, Los Angeles, 1980

3. Academic experience with institution rank and title:
- Senior Research Scientist, CEID, Yale University, 2015–present
- Lecturer, Mechanical Engineering & Materials Science, Yale University, 2015–present
- Associate Professor, Physics, Ohio University, 2001–2005
- Assistant Professor, Physics, Ohio University, 1996–2001
- Research Assistant Professor, University of Washington, 1995–1996
- Postdoctoral Researcher, University of Washington, 1991–1995
- Postdoctoral Researcher, Technion, Haifa, Israel, 1987–1990
- IBM Research Fellow, Princeton University, 1986–1987

4. Non-academic experience:
- Manager, Material and Process Science, Unilever Research, 2009–2013
- Group Leader, Product Physics, Unilever Research, 2005–2009

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Outstanding Teacher, College of Arts and Sciences, Ohio University, 2000

8. Service activities (within and outside Yale):
Within Yale:
- Ad Hoc Committee on Safety for Creating and Performing Arts Awards, 2015–present

9. Most important publications and/or presentations (last five years):
- J.M. Fegyveresi, R.B. Alley, D.E. Voigt, J.J. Fitzpatrick, and L.A. Wilen, "Instruments and methods: A case study of ice core bubbles as strain indicators," Annals of Glaciology **60** (2019) 8–19.
- R.W. Style, T. Sai, N. Fanelli, M. Ijavi, K. Smith-Mannschott, Q. Xu, L.A. Wilen, and E.R. Dufresne, "Liquid-liquid phase separation in an elastic network," Phys. Rev. X **8** (2018) 011028.
- L. Wilen, "Acoustic resonance spectroscopy of soft solids," J. Acoust. Soc. Am. **141** (2017) 956.

- V. Wilczynski , J. Zinter, and L. Wilen, “Teaching engineering design in an academic makerspace: Blending theory and practice to solve client-based problems,” American Society for Engineering Education Annual Conference Proceedings, 2016.
- L. Wilen, “Acoustic resonance spectroscopy and prospects for novel 3D-printed material design,” Colloquium, University of Louisiana, Lafayette, 2016.
- T. Bertrand, K. Kaczmarek, and L. Wilen, “Musical acoustics and instrument design: When engineering meets music,” Proceedings of the 41st International Computer Music Conference, University of North Texas (2015).

10. Professional development activities:
    - Visiting Scientist, ETH Zurich, Switzerland, May 2019
    - Visiting Scientist, ETH Zurich, Switzerland, May 2018
    - Visiting Scientist, ETH Zurich, Switzerland, May 2017
    - Workshop participant, 41st International Computer Music Conference, University of North Texas, 2015

1. Name and academic rank: Joseph Zinter
Lecturer and Research Scientist, Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Biomedical Engineering, Yale University, 2011
   - M.H.S. Medicine, Yale School of Medicine, 2011
   - M.S. Applied Physics, Cornell University, 2004
   - B.S. Applied Physics, Columbia University, 2002
   - B.A. Engineering, Fairfield University, 2000

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Lecturer and Research Scientist, 2019–present
   - Lecturer and Associate Research Scientist, 2012–2019
   - Design Preceptor, School of Engineering & Applied Sciences, Harvard University, 2011

4. Non-academic experience:
   - Clinical specialist, Cardiac Rhythm Management Division, Medtronic, Inc., 2004–2005

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
   - Teacher of the Year Award, Yale School of Medicine Med/Peds Residency Program, 2017
   - Classy Awards, Finalist, 2016
   - VentureWell E-Team Stage One Grant, 2015
   - Outstanding Mentor Award, Design for America, 2014
   - Yale Gibbs Distinguished Staff Award, 2014
   - First Academic Think Tank of Yachay, 2014
   - President’s Innovation Fund for Faculty, Harvard University, 2011
   - Yale University Associates in Teaching Program, 2010
   - Yale University Teaching Fellowship Prize, 2010
   - National Institute of Health T32 Fellowship, 2009
   - SPIE Photonics West Conference – Best Poster Award, 2009

8. Service activities (within and outside Yale):
   Within Yale:
   - Yale Global Health Initiative
   - Yale Sustainability Advisory Committee
   - Yale-Smithsonian Advisory Committee
   - Yale Center for Biomedical and Innovative Technologies Advisory Committee

- Yale Center for Collaborative Arts and Media Advisory Committee
- Yale Reaccreditation Advisory Subcommittee / Standard 5: Students

Outside Yale:

- K-12 outreach: Charter Oak School, Hamden County Day School, SCSU Science Educator Program, East Haven Science Teachers

9. Most important publications and/or presentations (last five years):
   - A. Ringlein, E. Olson, S. Gullapalli, A. Haggenmiller, H. Li, M. Emerson, A. Siefert, J. Zinter, and R. Torres, "Multiplatform virtual reality pathology," Pathology Informatics Summit, 2017.
   - J. Zinter, "Teaching at the intersection of disciplines," Vice Chancellor's Council of Deans (VCCD) Meeting, University of Auckland, New Zealand, 2017.
   - J. Zinter, "Maker spaces: Best practices," National Week of Making, the White House, Washington DC, 2016.
   - A.S. Muñoz-Abraham, R. Patrón-Lozano, R.R. Narayan, S.S. Judeeba, A. Alkukhun, T.I. Alfadda, J.T. Belter, D.C. Mulligan, R. Morotti, J.P. Zinter, and J.P. Geibel, "Extracorporeal hypothermic perfusion device for intestinal graft preservation to decrease ischemic injury during transportation," J. Gastrointestinal Surgery **20** (2016) 313–321
   - L.W. Buss, E.D. Buss, C.P. Anderson, M. Power, and J. Zinter, "Control of hydroid colony form by surface heterogeneity," PLoS ONE **11** (2016) e0156249.
   - J. Zinter, "Intersections," Keynote address at NSF Intersections Symposium, 2015.
   - R. Nia, M.H. Michalski, E. Brown, N. Doan, J. Zinter, N.T. Ouellette, and G.M. Shepherd, "Optimal directional volatile transport in retronasal olfaction," Proceedings of the National Academy of Sciences (PNAS) **112** (2015) 14700–14704.

10. Professional development activities:
    - Winterhouse Symposium on Design Education for Social Impact, Winterhouse Institute, University of Illinois at Chicago, 2017
    - National Academy of Advanced Teacher Education, Design Thinking Workshop, New Haven, CT, 2017
    - Spark Social Impact Conference, "Creating impactful products" (panel moderator), 2017
    - Scholar in Residence, Monestevole Estate, Umbria, Italy, 2014

1. Name and academic rank: Ronald S. Adrezin
Adjunct Lecturer of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Mechanical Engineering, Rutgers University, 1997
   M.E. Mechanical Engineering, The Cooper Union, 1988
   B.E. Mechanical Engineering, The Cooper Union, 1986

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Adjunct Lecturer, 2020
   - Professor, U.S. Coast Guard Academy, 2011–present
   - Associate Professor, U.S. Coast Guard Academy, 2008–2011
   - Associate Professor of Biomedical and Mechanical Eng., Univ. of Hartford, 2005–2008
   - Associate Director, Connecticut Space Grant College Consortium, 2006–2008
   - Associate Director, Institute for Life Support and Sustainable Living, 2005–2008
   - Assistant Professor of Biomedical and Mechanical Eng., Univ. of Hartford, 1997–2005
   - Exec. Dir., Center for Life Support and Sust. Living, Conn. College of Tech., 2007–2009
   - Chair, Institutional Review Board, Connecticut College of Technology, 2007–2008

4. Non-academic experience:
   - Patents (3 additional patents pending):
     - "Smart memory material lock devices," R. Adrezin, R. Dinan, S. Legum, and J. Nordyke, US Patent 9,697,708B2, issued Jul. 4, 2017.
     - "Smart memory material lock devices," R. Adrezin, R. Dinan, S. Legum, and J. Nordyke, US Patent 9,424,722B2, issued Aug. 23, 2016.
     - "Method and apparatus for gait measurement," R. Adrezin, M. Cordaro, F. Wang, and A. Fast, US Patent 5,511,571, issued Apr. 30, 1996.

5. Certifications or professional registrations: Professional Engineer, State of NY

6. Current membership in professional organizations: American Society of Mechanical Engineers (ASME)

7. Honors and awards:
   - Spirit of the Bear Award, USCGA, 2016
   - Letter of appreciation, Capt. J.R. Hamilton, Commanding Officer, USCGC Healy, 2015
   - Meritorious Team Commendation: Core Curriculum Task Force, 2015, and ABET, 2015
   - ASME Student Section Advisor Award (international award), 2007
   - Professor of the Year, Univ. of Hartford, College of Engineering, 1998, 1999, 2001, 2004
   - Teaching with Technology Award, University of Hartford, 2002
   - Office of Naval Research Fellowship for doctoral degree
   - Full tuition scholarship for bachelor's degree and master's degree

8. Service activities (within and outside Yale):

Outside Yale:

- Faculty adviser for Hillel (Jewish Club), USCGA, 2015–present
- Chair, Credentials Committee and Emeritus Sub-Committee, USCGA, 2011–present
- Core Curriculum Task Force, USCGA, 2011–2015
- AFGE Union Officer, USCGA, 2011–2015
- Equity Officer, USCGA, 2010–2012
- Lead adviser (dem), USCGA, 2009–2012, 2013–2014, 2017–2018
- Director of AIM (Academy Introduction Mission) for Engineering, USCGA, 2009–2012
- Hewitt Competition, USCGA, 2009–2011
- Academic adviser to 20+ cadets per year, USCGA, 2008–present
- Faculty adviser for undergraduate chapter of ASME, USCGA, 2008–present
- Science, Technology, and Engineering Program (STEP), USCGA, 2008–present
- Various search committees, USCGA

9. Most important publications and/or presentations (last five years):

- L. Dewhirst, K. Levy, S. Lyle, M. McKeown, I. Myer, Z. Velasquez, M. Johnson, R. Adrezin, and N. Haliscak, "Active seating system for medical researchers to develop ideal parameters to minimize pressure ulcers." BMES, 2019.
- J. Gray, R. Adrezin, and R. Sanders, "United States Coast Guard Academy corrosion projects," DoD–Allied Nations Technical Corrosion Conference, 2019.
- R.W. Freeman, R.S. Adrezin, and A. Foley, "Bilge pumps as introductory mechanical engineering design projects," ASEE Annual Conference, 2019.
- R. Adrezin and N. Haliscak, "Additive manufacturing potential on United States Coast Guard cutters for resilience in the Arctic," *Naval Eng. J.* **129** (2017) 111–121.
- R. Adrezin, M. Daeffler, B. Jared, R. Schaller, and E. Schindelholz, "Educating cadets on additive manufacturing: More optimal shapes but accelerated corrosion?", DoD–Allied Nations Technical Corrosion Conference, 2017.
- V. Wilczynski and R. Adrezin, "Higher education makerspaces and engineering education," *Proceedings of ASME International Mechanical Eng. Conf. & Expo.*, 2016.
- R. Adrezin, "U.S. Coast Guard Academy resilience efforts in remote environments," Additive Manufacturing Across the DoD (panel), 2nd ASME Additive Manufacturing + 3D Printing Conference & Expo, 2016.
- R. Adrezin and N. Haliscak, "Additive manufacturing at sea in the Arctic," AeroDef Manufacturing with Composites Manufacturing, 2016.

10. Professional development activities:

- Several NASA grants (co-PI) and Associate Director of the CT Space Grant Consortium
- Several NSF grants (co-PI), NSF grant reviewer, and NSF grant review session chair
- USCG Research and Development Center: Conducted research on buoy corrosion, 2018
- USCGC *Forward*: Conducted corrosion research while on patrol, 2018
- DoD Corrosion Policy and Oversight Office Grant: Conducting corrosion research along with USCGA cadets, 2017–present
- USCGC *Healy*: Member of research team in Arctic during ATE 2015
- DoD Systems Engineering Grant, PI on both RT19 and RT19A, 2010–2012

1. Name and academic rank: Sudhangshu Bose
Adjunct Lecturer of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Materials Science & Engineering, University of California, Berkeley, 1978
M.Sc. Physics, Ranchi University, India, 1964
B.Sc. Physics, St. Xavier's College, India, 1962

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Adjunct Lecturer, 2017–present
- Professor of Practice, Mechanical Engineering, Rensselaer Polytechnic Inst., 2010–2015
- Adjunct Professor, Mechanical Engineering, Rensselaer Polytechnic Inst., 2001–2010

4. Non-academic experience:
- Executive Consultant, Pratt & Whitney, 2018–present
- Fellow of High Temperature Materials and Coatings and Manager of Hot Section Alloy Group, Pratt & Whitney, 2001–2008
- Senior Materials / Analytical Engineer, Pratt & Whitney and UTC Fuel Cells, 1978–2001
- Patents: Over 24 patents issued and several still in the process

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Technical Adviser to Joint US–China Collaboration in Clean Energy (JUCCCE), 2012
- Leadership Award, Pratt & Whitney, 2003
- Special Award, Pratt & Whitney, 1994
- Eagle Award, Pratt & Whitney, 1990
- UTC Award for Extraordinary Achievement in Product Design, 1979
- Scholastic Achievement Award, ASM, Golden Gate Chapter, 1976, 1977
- Graduated with Honors, St. Xavier's College, 1962

8. Service activities (within and outside Yale): N/A

9. Most important publications and/or presentations (last five years): N/A

10. Professional development activities:
- Invited speaker:
  - Materials Science, University of Connecticut, 2012 and 2005
  - ASM International, Hartford Chapter, 2010
  - Thermal Spray Conference, Hartford, CT, 2008

- International Conference on Metallurgical Coatings and Thin Films, 2008
  - University of Central Florida, 2008
  - Case Western Reserve University, Materials Science 2007
  - Forum of Technology, 2006
  - International Conference on Science & Economy, 2005
  - Engineering Foundation Conference on Advanced Materials and Processes for Gas Turbines, 2002
  - NASA Thermal Barrier Coatings Workshop, 1996, 1997
- Expert reviewer, MIT Enterprise for Small Business, 2014

1. Name and academic rank: Ronald Lehrach
Adjunct Lecturer of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
M.S. Mechanical Engineering, Rensselaer Polytechnic Institute, 1965
B.S. Mechanical Engineering, Polytechnic Institute of Brooklyn, 1962

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Adjunct Lecturer, 2008–present

4. Non-academic experience:
- Consultant, Defense Advanced Research Projects Agency, 2001–2007
- Consultant, United Technologies Research Center, 1998–2000
- Program Manager, United Technologies Research Center, 1976–1998
- Senior Systems Engineer, United Technologies – Chemical Systems Division, 1974–1976
- Senior Research Engineer, United Technologies Research Center, 1966–1974
- Senior Analytical Engineer, Pratt & Whitney, 1962–1966
- Patents: 3 patents issued

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Institute of Aeronautics and Astronautics (AIAA)

7. Honors and awards:
- Member of U.S. government-sponsored Hypersonic Science and Technology Executive Independent Review Team tasked with providing an independent assessment of the hypersonic program in the U.S.
- U.S. delegate to the U.S./France Data Exchange Agreement conferences on hypersonic propulsion
- Outstanding Achievement Award for Hydrocarbon Scramjet Flowpath Development, United Technologies Research Center, 1998
- National AeroSpace Plane (NASP) Significant Achievement Award for Engine Concept Development, 1988
- Tau Beta Pi Engineering Honor Society
- Pi Tau Sigma Mechanical Engineering Honor Society

8. Service activities (within and outside Yale): N/A

9. Most important publications and/or presentations (last five years): N/A

10. Professional development activities: N/A

1. Name and academic rank: Alex Tsai
Adjunct Lecturer of Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mechanical Engineering, West Virginia University, 2007
M.S. Mechanical Engineering, Tufts University, 2002
B.S. Mechanical Engineering, University of Puerto Rico, Mayaguez Campus, 1998

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
- Adjunct Lecturer, 2017, 2019
- Assistant Professor, U.S. Coast Guard Academy, 2010–2014, 2015–present

4. Non-academic experience:
- Mechanical Engineer, Jacobs Engineering, Houston, TX, 2007–2009, 2014–2015
- Control Engineer and Postdoctoral Fellow, U.S. Department of Energy, National Energy Technology Laboratory, Morgantown, WV, 2009–2010
- Manufacturing Engineer, AirMaster Awning, Inc., Barceloneta, PR, 2003–2004
- Design Engineer, GE Aircraft Engines, Lynn, MA 2001–2002

5. Certifications or professional registrations: Professional Engineer, State of CT

6. Current membership in professional organizations: American Society of Mechanical Engineers (ASME)

7. Honors and awards: N/A

8. Service activities (within and outside Yale):
Outside Yale:
- Faculty adviser for Ping-Pong Club, USCGA, 2018–present
- Co-adviser for Fulbright Student Program, USCGA, 2015–present
- ABET program coordinator, Mechanical Engineering, USCGA, 2013–2019 visit
- ABET program contributor, Mechanical Engineering, USCGA, 2013 visit
- Faculty adviser for Fencing Club, USCGA, 2011–2012
- ASME Student Professional Development Conference for District A, 2011
- Academic adviser to 20+ cadets per year, USCGA, 2010–2014, 2015–present

9. Most important publications and/or presentations (last five years):
- A. Tsai, P. Pezzini, D. Tucker, and K. Bryden. "Multiple-model adaptive control of a hybrid solid oxide fuel cell gas turbine power plant simulator," J. Electrochem. En. Conv. Stor. **16** (2019) 031003.
- T. Emami, A. Tsai, and D. Tucker "Apply robust proportional integral derivative controller to a fuel cell gas turbine," J. Electrochem. En. Conv. Stor. 15 (2018) 021006.

- A. Tsai, D. Tucker, and T. Emami "Multiple model adaptive estimation of a hybrid solid oxide gas turbine power plant simulator," J. Electrochem. En. Conv. Stor. **15** (2018) 031004.
- A. Tsai, D. Tucker, and T. Emami "Adaptive control of a nonlinear fuel cell-gas turbine balance of plant simulation facility," J. Fuel Cell Sci. Technol. **11** (2014) 061002.

10. Professional development activities:
    - Session/track organizer and/or chair:
        - Controls, Diagnostics and Instrumentation Track, Advanced Controls for Gas Turbines Session (session organizer), ASME Turbo Expo, 2019
        - Smart and Cyberphysical Systems Track (track chair), ASME Power and Energy / Energy Sustainability Conference, 2018
        - Control, Diagnostics, and Instrumentation Track. Advanced Control for Components and Subsystems Session (session organizer and chair), ASME Turbo Expo, 2018
        - Fuel Cell Ancillary Systems and Balance of Plant Track (session chair), ASME 14th Fuel Cell Science, Engineering, and Technology Conference, 2016
        - Thermofluids and Thermodynamics of Energy Systems; Exergy Analysis; Systems Integration Track, Energy and Power Systems Integration and Operation Subtrack (session organizer), ASME 5th International Conference on Energy Sustainability, 2011

1. Name and academic rank: Oliver K. Baker
Professor of Physics

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Physics, Stanford University, 1987
   M.S. Mathematics, Stanford University, 1984
   M.S. Physics, Stanford University, 1984
   B.S. Physics, Massachusetts Institute of Technology, 1981

3. Academic experience with institution rank and title:
   - Director, Wright Nuclear Structure Lab, Yale University, 2010–2012
   - Professor, Physics, Yale University, 2006–present
   - Endowed University Professor, Physics, Hampton University, 2000–2006
   - Dean, School of Science, Hampton University, 2001
   - Adjunct Professor, Physics, Columbia University, 2000–2001
   - Professor, Physics, Hampton University, 1999–2000
   - Associate Professor, Physics, Hampton University, 1993–1999
   - Visiting Professor, Wayne State University, 1993
   - Assistant Professor, Physics, Hampton University, 1989–1993

4. Non-academic experience:
   - Consultant, Los Alamos National Laboratory, 1990–1992
   - Staff Physicist, Jefferson Lab, 1989–2006
   - Postdoctoral Fellow, Physics, Los Alamos National Laboratory, 1986–1988

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Physical Society (APS)

7. Honors and awards:
   - Edward Bouchet Award, American Physical Society
   - Elmer Imes Award for Outstanding Research, National Society of Black Physicists
   - US ATLAS Distinguished Researcher
   - Named lecturer at four universities (HBCUs) and organizations
   - Inductee, Arkansas Black Hall of Fame

8. Service activities (within and outside Yale):
   Within Yale:
   - Member of Science, Technology, and Research Scholars (STARS) Advisory Committee, Yale University (for underrepresented groups in STEM)
   - Member of various internal committees

   Outside Yale:
   - Director of research centers:

- Director, Ctr. for Study of Origin and Structure of Matter, Hampton Univ., 2002–2006
  - Co-Director, Center for Particle Physics, Hampton University, 1999–present
  - Acting Dir., Nuclear and High Energy Physics Res. Ctr., Hampton Univ., 1995–1996
- Member of national and international committees:
  - Entanglement in High Energy Collisions Workshop, 2018–present
  - BNL Associate Laboratory Director Search Committee, 2018
  - Dark Interactions Biannual International Workshop, 2014–present
  - FNAL PAC, 2009–2012
  - NSF Assistant Director Search Committee, 2009
  - LLNL Director's Review Committee, 2008
  - Jefferson Lab Director Search Committee, 2007
  - LBNL Physics Division Review Committee, 2006–present
  - NSF/DOE HEPAP Subpanel on University Research, 2006–2007
  - Fermi National Accelerator Laboratory Director Search Committee, 2004
  - HEPAP Subpanel on Accelerators and the COSMOS, 2003
  - US ATLAS Program Manager Search Committee, 2003
  - NSF/DOE High Energy Physics Advisory Panel (HEPAP), 2002–2005
  - Committee of Visitors, Department of Physics, Harvard University, 2001–2005
  - LBNL Nuclear Science Division Review Committee, 2001–2003
  - Graduate Admissions Committee for Physics, Columbia University, 2000–2001
  - NSF/DOE Nuclear Science Advisory Panel (NSAC), 1999–2001
  - Jefferson Lab Director Search Committee, 1999–2000
- Chair, US ATLAS Analysis Support Task Force, 2005
- Seminars, recruitment, etc. at HBCUs (e.g., Texas Southern Univ., Philander Smith College, Univ. of Arkansas at Pine Bluff, …)

9. Most important publications and/or presentations (last five years):
- O.K. Baker and D.E. Kharzeev, "Thermal radiation and entanglement in proton-proton collisions at the LHC," Phys. Rev. D **98** (2018) 054007.
- G. Aad, …, O.K.Baker, … (The ATLAS Collaboration), "Measurement of the Higgs boson coupling properties in the $H\rightarrow ZZ^*\rightarrow 4\ell$ decay channel at $\sqrt{\mathbf{s}} = 13$ TeV with the ATLAS detector," J. High Energy Physics **3** (2018) 095.
- G. Aad, …, O.K. Baker, … (The ATLAS Collaboration), "Measurement of inclusive and differential cross sections in the $H\rightarrow ZZ^*\rightarrow 4\ell$ decay channel in pp collisions at $\sqrt{\mathbf{s}} = 13$ TeV with the ATLAS detector", J. High Energy Physics **2017** (2017) 132.
- G. Aad, …, O.K. Baker, … (The ATLAS Collaboration), "Search for new light gauge bosons in Higgs boson decays to four-lepton final states in pp collisions at 8 TeV with the ATLAS detector," Phys. Rev. D **92** (2015) 092001.
- P. Slocum, O.K. Baker, J.L. Hirshfield, Y. Jiang, AT. Malagon, A. J. Martin, S. Shchelkunov, and A. Szymkowiak, NIM A **770** (2015) 76–86.

10. Professional development activities:
- Frequent reviewer for scientific journals

1. Name and academic rank: Helen Caines
Professor of Physics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Philosophy (Physics), University of Birmingham, U.K., 1996
B.S. Physics, University of Birmingham, U.K., 1992

3. Academic experience with institution rank and title:
- Professor, Physics, Yale University, 2019–present
- Associate Professor, Physics, Yale University, 2010–2019
- Assistant Professor, Physics, Yale University, 2004–2010
- Research Scientist, Physics, Yale University, 2001–2004
- Research Associate, Physics, The Ohio State University, 2000–2001
- Postdoctoral Researcher, Physics, The Ohio State University, 1996–2000

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Physical Society (APS), Fellow of the Institute of Physics (IOP) in the U.K., and member of the following collaborations:
- ALICE, CERN (1000 collaborators, 116 institutes, 33 countries): 2006–present
- STAR: 1996–present
- RHIC Collider at BNL (500 collaborators, 63 institutes, 13 countries)

7. Honors and awards:
- American Physical Society CSWP Woman Physicist of the Month (January), 2012
- "Enseignant Invité" (Invited Professor) Fellowship, Strasbourg University, France, 2005
- Engineering and Physical Sciences Research Council Advanced Research Fellowship, U.K., 2003

8. Service activities (within and outside Yale):
Within Yale:
- Member, Physics Graduate Admissions Committee, 2020
- Member, Course of Study Committee (university-wide), 2018–2020
- Member, Center for Teaching and Learning (CTL) Advisory Committee, 2016–2020
- Member, College Freshman Research Grant Committee, 2016–2019
- Member, Joint Committee for the Marshall, Mitchell, and Rhodes Scholarships, 2016–2017
- Chair, ITS Advisory committee, 2015–2017
- Member, Physics Graduate Admissions Committee, 2015–2016
- Member, Physics Graduate Admissions Committee, 2015

- Chair, Physics Climate and Diversity Committee, 2014–2020
- Member, Committee on Sexual Harassment (university-wide), 2014–2020
- Member, Physics Helmsley Teaching PostDoc Committee, 2014–2015
- Faculty mentor to STEM female post-docs through the Yale WISAY initiative

Outside Yale:

- Member, Brookhaven National Laboratory Task Force, 2018
- Chair, ALICE Diversity Task Force that was charged with a fact-finding mission to investigate what, if any issues existed in the ALICE collaboration, 2017
- Organizer, workshops and panel discussions at Brookhaven National Laboratory on both "Women and Minorities in Science" and "Science Education and Outreach"

9. Most important publications and/or presentations (last five years):
Dr. Caines is (co-)author on more than 450 published papers in refereed journals and has given more than 20 colloquia, seminars, and invited talks at conferences and workshops in the last five years. More details available upon request.

10. Professional development activities:
    - Yale Public Thought Leadership Fellow (worked with journalists from the OpEd Project), 2016–2017
    - Chair, "Careers outside academia" panel, Conf. for Undergrad. Women in Physics, 2015
    - Co-organizer, Yale Physics Olympiad (planned and ran events for students and teachers)
    - Frequent reviewer for scientific journals, such as Nature Communications, various APS journals, Journal of Physics G (IOP), Computer Phys. Commun., European Phys. J., etc.
    - Reviewer for research proposals for DOE, NSF, and US Civilian Research and Development Foundation, and for international research proposals

1. Name and academic rank: Stuart Campbell
Associate Professor of Biomedical Engineering

2. Degrees with disciplines, institutions, and dates:
Ph.D. Bioengineering, University of California, San Diego, 2010
B.S. Bioengineering, Washington State University, 2004

3. Academic experience with institution rank and title:
- Associate Professor, Biomedical Engineering, Yale University, 2017–present
- Assistant Professor, Biomedical Engineering, Yale University, 2012–2017
- Postdoctoral Researcher, Physiology, University of Kentucky, 2010–2012

4. Non-academic experience:
- Engineer, Decagon Devices, Inc., 2004–2005

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Biophysical Society (BPS), Biomedical Engineering Society (BMES), American Heart Association

7. Honors and awards:
- NSF CAREER Award, 2017
- Gordon Engineering Leadership Medal, UC San Diego, 2009
- Cardiovascular Science Scholarship Award, School of Medicine, UC San Diego, 2008

8. Service activities (within and outside Yale):
Within Yale:
- Medical Scientist Training Program Faculty Cmte., School of Medicine, 2017–present
- Graduate Admissions Committee, Biomedical Engineering, 2013–2017, 2020
- Faculty Advisory Group, Center for Engineering Innovation and Design, 2013–2015

Outside Yale:
- Frequent reviewer for scientific journals (J. Theoretical Biol., PLoS Comput. Biol., Biophys. J., Amer. J. Physiology: Cell Physiology, Cell. Molecular Bioeng., J. Exper. Biol., eLife Science, Circulation Res., Scientific Reports, J. Mol. Cell. Cardiol., J. Physiology, J. Biological Chem., Cardiovascular Eng. Technol., and J. General Physiol.)
- Guest editor:
  - PLoS Computational Biology, 2015
  - Biomarker Insights: Supplement on Stem Cells in Cardiovascular Biology, 2015

9. Most important publications and/or presentations (last five years):
- S.G. Campbell and S.A. Niederer, “KBTBD13 and the ever-expanding sarcomeric universe,” J. Clin. Invest. **130** (2020) 593–594.
- L.R. Sewanan, J. Schwan, J. Kluger, J. Park, D.L. Jacoby, Y. Qyang, and S.G. Campbell,

“Extracellular matrix from hypertrophic myocardium provokes impaired twitch dynamics in healthy cardiomyocytes,” JACC Basic Transl Sci. **4** (2019) 495–505.

- S.G. Campbell, Y. Qyang, and J.T. Hinson, “Sarcomere-directed calcium reporters in cardiomyocytes,” Circ Res. **124** (2019) 1151–1153.
- J.A. Clark and S.G. Campbell, “Diverse relaxation rates exist among rat cardiomyocytes isolated from a single myocardial region,” J. Physiol. **597** (2019) 711–722.
- S.A. Niederer, K.S. Campbell, and S.G. Campbell, “A short history of the development of mathematical models of cardiac mechanics,” J. Mol. Cell. Cardiol. **127** (2019) 11–19.
- K.S. Campbell, P.M.L. Janssen, and S.G. Campbell, “Force-dependent recruitment from the myosin off state contributes to length-dependent activation,” Biophys J. **115** (2018) 543–553.
- Y. Aboelkassem and S.G. Campbell, “Acute optogenetic modulation of cardiac twitch dynamics explored through modeling,” J. Biomech. Eng. **138** (2016) 1110051.
- L.R. Sewanan, J.R. Moore, W. Lehman, and S.G. Campbell, “Predicting effects of tropomyosin mutations on cardiac muscle contraction through myofilament modeling,” Front Physiol. **7** (2016) 473.
- B.C. Dash, K. Levi, J. Schwan, J. Luo, O. Bartulos, H. Wu, C. Qiu, T. Yi, Y. Ren, S. Campbell, M.W. Rolle, and Y. Qyang, “Tissue-engineered vascular rings from human iPSC-derived smooth muscle cells,” Stem Cell Reports **7** (2016) 19–28.
- C. Wang, J. Schwan, and S.G. Campbell, “Slowing of contractile kinetics by myosin-binding protein C can be explained by its cooperative binding to the thin filament,” J. Mol. Cell. Cardiol. **96** (2016) 2–10.
- Y. Aboelkassem, D. Savic, and S.G. Campbell, “Modeling predicts a connection between sinus vortex effects and aortic compliance,” J. Theor. Biol. **389** (2016) 306–309.
- Y. Aboelkassem, J.A. Bonilla, K.J. McCabe, and S.G. Campbell, “Contributions of Ca2+-independent thin filament activation to cardiac muscle function,” Biophys. J. **109** (2015) 2101–2112.

10. Professional development activities:
    - Grant reviewer:
        - American Heart Association, Basic Cardiovascular Science, 2013–present
        - NSF Biomechanics/Mechanobiology Program, 2016, 2018
        - Saving Tiny Hearts Society

1. Name and academic rank: Joseph T. Chang
Professor of Statistics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Statistics, Stanford University, 1989
M.S. Operations Research, Stanford University, 1985
M.S. Mathematics, Stanford University, 1982
B.S. Mathematics, Case Western Reserve University, 1980

3. Academic experience with institution rank and title:
- Professor, Statistics, Yale University, 1999–present
- Visiting Associate Professor, Applied Mathematics & Statistics, University of California, Santa Cruz, 1998–1999
- Associate Professor, Statistics, Yale University, 1996–1999
- Assistant Professor, Statistics, Yale University, 1989–1996

4. Non-academic experience:
- Consultant, Learning Systems Department, Siemens Corporate Research, 1993
- Consultant, National Security Agency, 1993–present
- Summer Research Fellow, Pfizer Corporation, 1991
- Cryptologic Mathematician, National Security Agency, 1990
- Summer Intern, IBM Corporation, 1980–1983

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Statistical Association (ASA)

7. Honors and awards:
- Lex Hixon Prize for Teaching Excellence in the Social Sciences, Yale University, 2014
- William Clyde DeVane Medal, Yale University, 1998

8. Service activities (within and outside Yale):
Within Yale:
- Member, Social Sciences Divisional Committee
- Member, Tenure and Appointments Committee, 2015–present
- Chair, Quantitative Reasoning Council, 2010–present
- Chair, Statistics, 2006–2012
- Member, Committee on Interdisciplinary Statistics Teaching, 1997
- Member, Yale Course of Study Committee, 1996–1997
- Director of Undergraduate Studies for Statistics, 1991–2000
- Co-author of Statistics Department Ph.D. qualifying exam, usually with a different second faculty member each year
- Adviser for senior projects in Mathematics, Applied Mathematics and Statistics

- First-year adviser, Timothy Dwight College

Outside Yale:

- Numerous invited talks at national and international conferences
- Organizer, session on evolution, IMS Annual Meeting, Chicago, 1996
- Organizer of invited paper session on hidden Markov models, IMS Conference, Cleveland, 1994
- Member of Program Committee, Interdisciplinary Neural Information Processing Systems Conference (joint meeting of IEEE Information Theory Society, American Physical Society, and Society for Neuroscience), 1990

9. Most important publications and/or presentations (last five years):
   - S.A. Kornilov, N. Rakhlin, R. Koposov, M. Lee, C. Yrigollen, A.O. Caglayan, J.S. Magnuson, S. Mane, J.T. Chang, and E.L. Grigorenko, "Genome-wide association and exome sequencing study of language disorder in an isolated population," Pediatrics **137** (2016) e20152469.
   - D.J. Campbell, J. Chang, and K. Chawarska, "Early generalized overgrowth in autism spectrum disorder: Prevalence rates, gender effects, and clinical outcomes," J. American Academy of Child & Adolescent Psychiatry **53** (2014) 1063–1073.
   - D. Campbell, J. Chang, K. Chawarska, and F. Shic, "Saliency-based Bayesian modeling of dynamic viewing of static scenes," in Proceedings of the Symposium on Eye Tracking Research and Applications (2014) 51–58.

10. Professional development activities:
    - Reviewer for Annals of Applied Probability, Annals of the Institute of Statistical Mathematics, Annals of Probability, Annals of Statistics, Biometrika, J. American Statistical Association, IEEE Transactions on Information Theory, Information and Computation, and Mathematical Biosciences
    - Lead, Statistical Analysis Core for the NIH Autism Center of Excellence program centered at the Yale Child Study Center

1. Name and academic rank: Stanley C. Eisenstat
Professor of Computer Science

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Mathematics, Stanford University, 1972
   M.S. Mathematics, Stanford University, 1987
   B.S. Mathematics, Case Institute of Technology, 1966

3. Academic experience with institution rank and title:
   - Professor, Computer Science, Yale University, 1982–present
   - Associate Professor, Computer Science, Yale University, 2076–2082
   - Assistant Professor, Computer Science, Yale University, 1972–1976
   - Lecturer, Computer Science, Yale University, 1971–1972

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the Society for Industrial and Applied Mathematics (SIAM), Association for Computing Machinery (ACM), American Mathematical Society (AMS), Mathematical Association of America (MAA)

7. Honors and awards:
   - SIAM Activity Group on Linear Algebra Best Paper Prize, 1997

8. Service activities (within and outside Yale):
   Within Yale:
   - Former Director of Undergraduate Studies, Computer Science
   - Member of a variety of departmental and university-wide committees

   Outside Yale:
   - Editorships:
     - Associate Editor, *Journal of the ACM*
     - Editorial Board Member, *SIAM J. Matrix Analysis and Applications*

9. Most important publications and/or presentations (last five years): N/A

10. Professional development activities: N/A

1. Name and academic rank: Rong Fan
Associate Professor of Biomedical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Materials Chemistry, University of California, Berkeley, 2006
M.S.	Applied Chemistry and Solid State Physics, Univ. of Science & Tech., China, 2001
B.S.	Applied Chemistry, University of Science & Technology, China, 1999

3. Academic experience with institution rank and title:
- Associate Professor, Biomedical Engineering, Yale University, 2014–present
- Assistant Professor, Biomedical Engineering, Yale University, 2010–2014
- Postdoctoral Researcher, California Institute of Technology, 2006–2009

4. Non-academic experience:
- 18 U.S. patents issued and 13 international patents issued

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of American Institute for Medical and Biological Engineering (AIMBE), Biomedical Engineering Society (BMES), Society for Immunotherapy of Cancer (SITC), Chemical and Biological Microsystems Society (CBMS), American Association for Cancer Research (AACR)

7. Honors and awards:
- Senior Member, National Academy of Inventors, 2019
- Rising Star Award, Cellular and Molecular Bioengineering (CMBE), BMES, 2016
- NSF CAREER Award, 2014
- Packard Fellowship for Science and Engineering, 2012
- Gold Medal – Graduate Student Award, Materials Research Society (MRS), 2006
- Regents Fellowship, University of California, Berkeley, 2001
- Ying-Gang Peng Scholarship for the Excellence of Graduate Research. University of Science and Technology of China, 2000

8. Service activities (within and outside Yale):

Within Yale:
- Member of various internal and university-wide committees (e.g., Stem Cell Center Advisory Cmte., Scholar Awards Cmte., Cleanroom Advisory Cmte., Faculty Advisory Cmte. for Center for Genomic Analysis, Graduate Admissions Cmte., Funds and Fellowship Cmte., CEID Faculty Advisory Board, and departmental search committees)
- Yale TEDx Resonance Outreach Program speaker, 2014

Outside Yale:
- Reviewer for numerous scientific journals including Sci. Transl. Med., Sci. Advances, Nat. Biomed.Eng., Nature Methods, Nature Communications, J. Clinical Investigation (JCI),

PNAS, Scientific Reports, Lab on a Chip, Integrative Biology, JACS, Nano Letters, ACS Nano, Small, Trends of Biotechnology, Cancer Research, Biomaterials, etc

- Scientific advisory board member:
  - Bio-Techne (R&D Systems/ProteinSimple/ACD)
  - IsoPlexis (also co-founder)
  - Singleron Biotechnologies (also co-founder)
- Conference or workshop (co-)organizer:
  - Microfluidics for Hematology Conference, 2018
  - "Mat. sci., tech., & devices for cancer modeling, diagnosis, & treatment," MRS, 2015
  - "Micro/nanofluidics for materials synthesis and bioanalytical appls.," MRS, 2014
  - "Micro- and nanofluidics," MRS, 2011
- Editorial service:
  - Editorial Board Member, Scientific Reports
  - Guest Editor, special issue of Frontiers in Oncology, 2012

9. Most important publications and/or presentations (last five years):

- Y. Xiao, C. Liu, Z. Chen, M.R. Blatchley, J. Zhou, M. Xu, S. Gerecht, and R. Fan, "Senescent cells with augmented cytokine production for microvascular bioengineering and tissue repairs," Advanced Biosystems **3** (2019) 1900089.
- M. Janiszewska, D.P. Tabassum, Z. Castrano, S. Cristea, N.L. Kingston, M. Ekram, N.W. Harper, M. Kwak, Y. Qin, T. Laszewski, K. Nakamura, A. Luoma, A. Marusyk, K.W. Wucherpfennig, R. Fan, F. Michor, S. McAllister, and K. Polyak, "Subclonal cooperation drives metastasis through modulating local and systemic immune microenvironments, Nature Cell Biology **21** (2019) 879.
- I. Xhangolli, B. Dura, G.H. Lee, D.J. Kim, Y. Xiao, and R. Fan, "Single-cell integrative analysis of CAR-T cell activation reveals a predominantly TH1/TH2 mixed response independent of differentiation," Genomics Proteomics Bioinformatics **17** (2019) 129–139.
- N. Wang, J. Zheng, Z. Chen, Y. Liu, B. Dura, M. Kwak, J. Xavier-Ferrucio, Y.-C. Lu, M.M. Zhang, C. Roden, J.J. Cheng, D. Krause, Y. Ding, R. Fan, and J. Lu, "Single-cell microRNA/mRNA co-profiling reveals non-(epigenetic) heterogeneity and regulatory programs," Nature Communications **10** (2019) 95.
- Z. Chen, Y. Lu, K. Zhang, Y. Xiao, J. Lu, and R. Fan "Multiplexed, sequential secretion analysis of the same single cells reveals distinct effector response dynamics dependent on the initial basal state," Advanced Science **6** (2019) 1801361.
- Z. Chen, J.J. Chen, and R. Fan**, "**Single-cell protein secretion detection and profiling," Annual Review of Analytical Chemistry **12** (2019) 21.
- Y.X. Deng, A. Finck, and R. Fan**, "**Single-cell omics analyses enabled by microchip technologies," Annual Review of Biomedical Engineering **21** (2019) 365–393.
- Y. Xiao, D.J. Kim, B. Dura, K. Zhang, R.C. Yan, H.M. Li, E. Han, J. Ip, P. Zou, J. Liu, A.T. Chen, A.O. Vortmeyer, J.B. Zhou, and R. Fan, "Ex vivo dynamics of human glioblastoma cells in a microvasculature-on-a-chip system correlates with tumor heterogeneity and subtypes," Advanced Science **6** (2019) 1801531.

10. Professional development activities:

- Grant reviewer: NIH, 2018; National Cancer Institute, 2012–present; NSF, 2014–2015.
- Judge, Teptu Brink Greater NY Area HS Science Competition, 2015–2016

1. Name and academic rank: Bonnie T. Fleming
Professor of Physics

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Physics, Columbia University, 2002
M.Phil.	Physics, Columbia University, 1999
M.A.	Physics, Columbia University, 1998
B.S.	Physics, Barnard College, Columbia University, 1993

3. Academic experience with institution rank and title:
    - Professor, Physics, Yale University, 2013–present
    - Horace D. Taft Associate Professor, Physics, Yale University, 2009–2013
    - Associate Professor, Physics, Yale University, 2008–2009
    - Assistant Professor, Physics, Yale University, 2002–2008

4. Non-academic experience:
    - Deputy Chief Research Officer, Fermi National Accelerator Laboratory, 2016–2018

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Physical Society (APS), Connecticut Academy of Science and Engineering, and member of the following collaborations:
    - SBND (originally LAr1-ND): Member, 2014–present
    - LArIAT: Member, 2012–present
    - LAr1: Member and Collaboration Contact, 2012–2014
    - DUNE/LBNF: Member & Inst. Board Rep., 2014–present; Exec. Board, 2015–2017
    - LBNE: Member & Inst. Board Rep., 2009–present; Exec. Board, 2009–2012, 2014–2015
    - MicroBooNE (E974): Founding Sci. Spokesperson 2007–2012; Sci. Co-Spokesperson, 2012–present
    - ArgoNeuT (T962): Founding Sci. Spokesperson, 2006-2009; Member, 2006–present
    - FINeSSE: Co-Spokesperson, 2002–2005
    - BooNE (E898): Member, 1997–2009
    - CTEQ: Member, 1997–2001
    - CCFR/NuTeV (E815): Member, 1997–present

7. Honors and awards:
    - American Physical Society DPF Mentoring Award, 2018
    - Fellow of the American Physical Society, 2014
    - Public Voices Fellowship, Yale University, 2013–2014
    - Seton Elm Ivy Award, Yale University, 2012
    - Kavli Frontier Fellow, National Academy of Sciences, 2007
    - Junior Faculty Fellowship, Yale University, 2007

- NSF CAREER Award, 2006
- Luise Meyer-Schutzmeister Award, Association of Women in Science, 2001

8. Service activities (within and outside Yale):

Within Yale:

- Director of Graduate Studies for Physics, 2019–present
- Frequent member of a variety of internal committees (e.g., searches, library, curriculum, ROTC advisory, faculty diversity, tenure and appointments, departmental planning, etc.)
- First-year academic adviser, 2005–2006, 2011–2012

Outside Yale:

- Faculty advisor/mentor for Conf. for Undergrad. Women in Physics, 2007, 2008, 2011
- Girls Science Investigations: GSI New Haven, Founder and Co-Director, 2006–present
- Co-founder and organizer, Girls Science Salon, a Saturday program for 6^{th}- to 8^{th}-grade girls at Fermilab, 2002–2004

9. Most important publications and/or presentations (last five years):

- P. Abratenko et al., "Search for heavy neutral leptons decaying into muon-pion pairs in the MicroBooNE Detector," submitted.
- R. Acciarri et al., "Improved limits on millicharged particles using the ArgoNeuT experiment at Fermilab," submitted.
- C. Adams et al., "Reconstruction and measurement of O(100) MeV energy electromagnetic activity from $\pi 0 \rightarrow \gamma\gamma$Decays in the MicroBooNE LArTPC," submitted.
- C. Adams et al., "A method to determine the electric field of liquid argon time projection chambers using a UV laser system and its application in MicroBooNE," submitted.
- W. Foreman et al., "Calorimetry for low-energy electrons using charge and light in liquid argon," Phys. Rev. D **101** (2020) 012010.
- P. Abratenko et al. "First measurement of inclusive muon neutrino charged current differential cross sections on argon at $E\nu \sim 0.8$ GeV with the MicroBooNE Detector," Phys. Rev. Lett. **123** (2019) 131801.
- C. Adams et al., "Design and construction of the MicroBooNE Cosmic Ray Tagger system," J. Instrumentation **14** (2019) P04004.
- C. Adams et al., "Rejecting cosmic background for exclusive charged current quasi elastic neutrino interaction studies with Liquid Argon TPCs; a case study with the MicroBooNE detector," European Physical J. C **79** (2019) 673.

10. Professional development activities:

- Physics Colloquium Committee member, 2019–present
- Women and Power Summit, Holton Arms School, 2019
- Yale Physics Professional Development Organization (YPPDO) seminar series on careers in academia, "Putting together an application," 2019
- Public lecture, LBNF/DUNE, Neutrino Day, Summer Undergraduate Research Fellowship (SURF) program at Yale, 2017
- Co-organizer, Yale Physics Olympiad (planned and ran events for students and teachers), 2004, 2005
- Frequent reviewer for several scientific journals

1. Name and academic rank: Anjelica L. Gonzalez
Associate Professor of Biomedical Engineering

2. Degrees with disciplines, institutions, and dates:
Ph.D. Computational Biology, Baylor College of Medicine, 2004
B.S. Biological Engineering, Utah State University, 1999

3. Academic experience with institution rank and title:
- Associate Professor, Biomedical Engineering, Yale University, 2015–present
- Donna L. Dubinsky Assistant Professor, Biomedical Engineering, Yale Univ., 2014–2015
- Assistant Professor, Biomedical Engineering, Yale University, 2009–2014
- Postdoctoral Researcher, Vasular Biology and Therapeutics, Yale Univ., 2007–2009

4. Non-academic experience:
- Postdoctoral Researcher, Leukocyte Biology, Texas Children's Hospital, 2004–2006

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of American Institute of Medical and Biological Engineers (AIMBE), Biomedical Engineering Society (BMES), American Heart Association (AHA), North American Vascular Biology Organization

7. Honors and awards:
- BMES Diversity Award, 2017
- BMES Cellular and Molecular Bioengineering Young Innovator Award, 2015
- Provost's Teaching Prize, Yale University, 2014
- 10 Latino Innovators, NBC Universal, 2012
- NIH Pediatric Loan Repayment Program Award (competitive renewal), 2007
- Gordon Research Conf. on Basement Membranes Carl Storm Fellowship Award, 2006
- American Society for Investigative Pathology FASEB MARC Program Oral Presentation Award, 2006
- American Physiological Society (APS)/NIDDK Fellowship, 2004–2006
- Keystone Symposia Scholarship Award, 2005
- NIH Pediatric Loan Repayment Program Award, 2004

8. Service activities (within and outside Yale):
Within Yale:
- Member of various internal committees (e.g., Teaching, Learning, and Advising Cmte., Global Health Fellows Program Selection Cmte., Vic Tyler Lectureship Cmte., etc.)
- Invited speaker at internal events (e.g., Yale Women in Science Seminar, Yale MMAS Familia [minority math and science family] Lecture, La CASA Faculty Lecture, Public Health Coalition Luncheon, National Society of Black Engineers Seminar, etc.)
- Panelist (Office of Postdoctoral Affairs "Academic Job Search Series for Scientists"

panel, Graduate Writing Center "Women in Scientific Publication" panel, etc.)
- Advisory Group, Center for Engineering Innovation and Design development

Outside Yale:
- Board of Directors, Biomedical Engineering Society, 2017–present
- Distinguished Faculty Member, NSF Int'l Summer School on Biocomplexity, 2013
- Invited speaker and panelist, NSF/JSPS US–Japan Connection Symposium for Leaders in Science, Technology, Engineering, and Mathematics
- Keynote speaker:
  - Microcirculatory Society President's Lecture, 2017
  - Women in Science at Yale (WISAY), 2013
  - Mosa Mack Science Detective K-12 Launch Event
  - FIRST Robotics Competition
  - UCONN Summer Research Scientific Symposium, 2009
- Invited speaker at various teaching/mentoring events (Yale-New Haven Teachers Institute, Southern Connecticut State University's Science Teachers Institute, UCONN's Many Mentors, etc.)
- Newsweek/Womensphere Emerging Leaders Global Summit Speaker, 2011

9. Most important publications and/or presentations (last five years):
   - A.S. Pellowe, M. Sauler, Y. Hou, J. Merola, R. Liu, B. Calderon, H.M. Lauridsen, M.R. Harris, L. Leng, Y. Zhang, P.V. Tilstam, J.S. Pober, R. Bucala, P.J. Lee, and A.L. Gonzalez, "Endothelial cell-secreted MIF reduces pericyte contractility and enhances neutrophil extravasation," FASEB J. **33** (2019) 2171–2186.
   - R. Matta, S. Lee, N. Genet, K. Hirschi, J.L. Thomas, and A.L. Gonzalez, "Minimally invasive delivery of microbeads with encapsulated, viable and quiescent neural stem cells to the adult subventricular zone," Sci. Rep. **9** (2019) 17798.
   - H. Sun, Y. Zhu, H. Pan, X. Chen, J.L. Balestrini, T.T. Lam, J.E. Kanyo, A. Eichmann, M. Gulati, W.H. Fares, H. Bai, C.A. Feghali-Bostwick, Y. Gan, X. Peng, M.W. Moore, E.S. White, P. Sava, A.L. Gonzalez, Y. Cheng, L.E. Niklason, and E.L. Herzog, "Netrin-1 regulates fibrocyte accumulation in the decellularized fibrotic sclerodermatous lung microenvironment and in bleomycin-induced pulmonary fibrosis," Arthritis Rheumatol. **68** (2016) 1251–1261.
   - A.S. Pellowe and A.L. Gonzalez, "Extracellular matrix biomimicry for the creation of investigational and therapeutic devices," Wiley Interdiscip. Rev. Nanomed. Nanobiotechnol. **8** (2016) 5–22.
   - L.A. Brown, P. Sava, C. Garcia, and A.L. Gonzalez, "Proteomic analysis of the pericyte derived extracellular matrix," Cell. Mol. Bioeng. **8** (2015) 349–363.
   - P. Sava, I.O. Cook, R.S. Mahal, and A.L. Gonzalez, "Human microvascular pericyte basement membrane remodeling regulates neutrophil recruitment," Microcirculation **22** (2015) 54–67.

10. Professional development activities:
    - Author of an op-ed article in the New York Times, 2013
    - Reviewer for Nanomedicine, J. Leukocyte Biology, BMC Cardiovascular Disorders, Cell. Mol. Bioeng., Biotechnology Progress, Annals of Biomedical Engineering, and PNAS

1. Name and academic rank: Juan Lora
Assistant Professor of Geology & Geophysics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Planetary Sciences, University of Arizona, 2014
B.S. Astronomy, University of Southern California, 2009

3. Academic experience with institution rank and title:
- Assistant Professor, Geology & Geophysics, Yale University, 2019–present
- Postdoctoral Fellow, University of California, Los Angeles, 2014–2018

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Astronomical Society (AAS), American Geophysical Union (AGU)

7. Honors and awards:
- University of California Chancellor's Fellowship, 2017–2019
- California Alliance Fellow, 2017–2019
- NASA Planetary Science Early Career Fellowship, 2017
- Gerard P. Kuiper Memorial Award, University of Arizona, 2014
- College of Science Teaching/Mentoring Award, University of Arizona, 2011

8. Service activities (within and outside Yale):
Within Yale:
- Member of departmental committees

Outside Yale:
- Associate Editor, Icarus
- Reviewer for scientific journals (Geophysical Res. Letters, Icarus, J. Hydrometeorology, Nature Astronomy, Nature Commun., Nature Geoscience, Planetary and Space Science, and Scientific Reports)
- Panelist and external reviewer for multiple NASA and NSF proposal review panels

9. Most important publications and/or presentations (last five years):
- S.P. Faulk, J.M. Lora, J.L. Mitchell, and P.C.D. Milly, "Titan's climate patterns and surface methane distribution due to the coupling of land hydrology and atmosphere," Nature Astronomy **4** (2020) 390–398.
- J. Lora and D. Ibarra, "The North American hydrologic cycle through the last deglaciation," Quaternary Sci. Rev. **226** (2019) 105991.J. Lora, T. Kataria, and P. Gao, "Atmospheric circulation, chemistry, and infrared spectra of Titan-like exoplanets around different stellar types," The Astrophysical J. **23** (2018) 58.

- S. Hill, J. Lora, N. Khoo, S. Faulk, and J. Aurnou, “Affordable rotating fluid demonstrations for geoscience education: The DIYnamics project,” Bull. Amer. Meteorological Soc. **99** (2018) 2529–2538.
- J. Lora and M. Ádámkovics, “The near-surface methane humidity on Titan,” Icarus **286** (2017) 270–279.
- J. Lora, J. Mitchell, C. Risi, and A. Tripati, “North Pacific atmospheric rivers and their influence on western North America at the Last Glacial Maximum,” Geophys. Res. Letters **44** (2017) 1051–1059.
- J. Mitchell and J. Lora, “The climate of Titan,” Ann. Rev. Earth and Planetary Sciences **44** (2016) 353–380.
- J. Lora, J. Lunine, and J. Russell, “GCM simulations of Titan’s middle and lower atmosphere and comparison to observations,” Icarus **250** (2015) 516–528.
- J. Lora and J. Mitchell, “Titan’s asymmetric lake distribution mediated by methane transport due to atmospheric eddies,” Geophys. Res. Letters **42** (2015) 6213–6220.
- J. Lora, “Components and mechanisms of hydrologic cycle changes over North America at the Last Glacial Maximum,” J. Climate **31** (2018) 7035–7051.

10. Professional development activities:
    - Co-leader, DIYnamics outreach program for creating affordable and accessible Earth and planetary science demonstration and teaching materials (diynamics.github.io)
    - Guest interviewee:
      - AAS Afternoon Astronomy Coffee Hour Hangout, 2018
      - Windfall Films TV series on the Cosmos, 2016
    - Organizing committee member and public talks coordinator, Exploring Your Universe, UCLA, 2015
    - Artist, volunteer, and exhibitor at Art of Planetary Science Art Shows, DPS Meetings, 2013–2016

1. Name and academic rank: James M. Mayer
   Charlotte Fitch Roberts Professor of Chemistry

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Chemistry, California Institute of Technology, 1982
   A.B. Chemistry, Harvard University, 1978

3. Academic experience with institution rank and title:
   - Charlotte Fitch Roberts Professor, Chemistry, Yale University, 2016–present
   - Professor, Chemistry, Yale University, 2014–2016
   - Visiting Professor, Chemistry, Weizmann Institute of Science, Israel, 2014
   - Alvin L. and Verla R. Kwiram Professor, Chemistry, Univ. of Washington, 1999–2014
   - Professor, Chemistry, University of Washington, 1992–1999
   - Associate Professor, Chemistry, University of Washington, 1989–1992
   - Assistant Professor, Chemistry, University of Washington, 1984–1989

4. Non-academic experience:
   - Visiting Scientist, E.I. DuPont de Nemours & Co., 1982–1984

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Association for the Advancement of Science (AAAS), Fellow of the American Chemical Society (ACS)

7. Honors and awards:
   - Frontiers in Chemical Energy Science Award, Max Planck Institute for Chemical Energy Conversion, 2019
   - ACS Award in Inorganic Chemistry, 2018
   - Inaugural Paul Hopkins Faculty Award, University of Washington, 2004
   - Innovation Recognition Program Awardee, Union Carbide, 1990, 1991
   - Polyhedron Best Paper Award, 1989
   - Sloan Research Fellowship, Alfred P. Sloan Foundation, 1989
   - Presidential Young Investigator, National Science Foundation, 1988
   - Herbert Newby McCoy Award, California Institute of Technology, 1982
   - Numerous named lectureships at universities throughout the US and internationally

8. Service activities (within and outside Yale):
   Within Yale:
   - Frequent member of a variety of internal committees (search committees, etc.)

   Outside Yale:
   - Editorships:
     - Associate Editor, Inorganic Chemistry, ACS, 2001–2018
     - Editorial Advisory Board, Accounts of Chemical Research, 2012–present

- Conference chair:
  - Gordon Research Conference on Metals in Biology, 2015
  - Gordon Research Conference on Inorganic Reaction Mechanisms, 2003
- Chair, ACS Division of Inorganic Chemistry, 2000

9. Most important publications and/or presentations (last five years):
   - A.C. Brezny, S.I. Johnson, S. Raugei, and J.M. Mayer, "Selectivity-determining steps in O_2 reduction catalyzed by iron(tetramesitylporphyrin)" J. Am. Chem. Soc. **142** (2020) 4108–4113.
   - S.M. Laga, T.M. Townsend, A.R. O'Connor, and J.M. Mayer, "Cooperation of cerium oxide nanoparticles and soluble molecular catalysts for alcohol oxidation," Inorg. Chem. Frontiers **7** (2020) 1386–1393.
   - M.M. Walker, B. Koronkiewicz, C. Shuming, K.N. Houk, J.M. Mayer, and J.A. Ellman, "Highly diastereoselective functionalization of piperidines by photoredox catalyzed C–H arylation and epimerization," J. Am. Chem. Soc. **142** (2020) 8194–8202.
   - Q.J. Bruch, G.P. Connor, C.H. Chen, P.L. Holland, J.M. Mayer, F. Hasanayn, and A.J.M. Miller, "Dinitrogen reduction to ammonium at rhenium utilizing light and proton-coupled electron transfer," J. Am. Chem. Soc. **141** (2019) 20198–20208.
   - D.J. Martin, B.Q. Mercado, and J.M. Mayer, "Combining scaling relationships overcomes rate vs. overpotential tradeoffs in O_2 molecular electrocatalysis," Sci. Adv. **6** (2020) eaaz3318.
   - T.J. Zerk, C.T. Saouma, J.M. Mayer, and W.B. Tolman, "Low reorganization energy for electron self-exchange by a formally copper(III/II) redox couple," Inorg. Chem. **58** (2019) 14151–14158.
   - D.J. Martin, B.Q. Mercado, and J.M. Mayer, "Synthesis and prior misidentification of 4-tert-butyl-2,6-dinitrobenzaldehyde," J. Org. Chem. **84** (2019) 12172–12176.
   - "Electrochemically determined O–H bond dissociation free energies of NiO electrodes predict proton-coupled electron transfer reactivity," C.F. Wise and J.M. Mayer, J. Am. Chem. Soc. 141 (2019) 14971-14975.
   - "Hydrogen on cobalt phosphide," M.F. Delley, Z. Wu, M.E. Mundy, D. Ung, B.M. Cossairt, H. Wang, and J.M. Mayer, J. Am. Chem. Soc. 141 (2019) 15390-15402.
   - G.P. Connor, B.Q. Mercado, H.S. Lant, J.M. Mayer, and P.L. Holland, "Chemical oxidation of a coordinated PNP-pincer ligand forms novel Re-nitroxide complexes with reversal of nitride reactivity," Inorg. Chem. **58** (2019) 10791–10801.
   - C.T. Saouma, C.-C. Tsou, S.R. Richard, R. Ameloot, F. Vermoortele, S. Smolders, B. Bueken, A.G. DiPasquale, W. Kaminsky, C.N. Valdez, D.E. De Vos, and J.M. Mayer, "Sodium-coupled electron transfer reactivity of metal-organic frameworks containing titanium clusters: The importance of cations in redox chemistry," Chem. Sci. **10** (2019**)** 1322–1331.

10. Professional development activities:
    - Frequent reviewer for scientific journals
    - Keynote speaker, Richard Larock Undergraduate Research Symposium, UC Davis, 2012
    - Keynote speaker, Gordon Research Conference on Molybdenum and Tungsten Enzymes, 2007

1. Name and academic rank: Kathryn Miller-Jensen
Associate Professor of Biomedical Engineering
and Molecular, Cellular, & Developmental Biology

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Chemical Engineering, Massachusetts Institute of Technology, 2006
   - B.E. Engineering Science, Dartmouth College, 1998
   - A.B. Engineering Science, Dartmouth College, 1997

3. Academic experience with institution rank and title:
   - Associate Professor, Biomedical Engineering and Molecular, Cellular, & Developmental Biology, Yale University, 2016–present
   - Assistant Professor, Molecular, Cellular, & Developmental Bio., Yale Univ., 2011–2016
   - Assistant Professor, Biomedical Engineering, Yale University, 2010–2016
   - Postdoctoral Research, Quantitative Bioscience, Univ. of California, Berkeley, 2007–2010

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Biomedical Engineering Society (BMES)

7. Honors and awards:
   - NSF CAREER, 2015
   - Ackerman Award for Teaching and Mentoring, Yale University, 2015
   - Cellular and Molecular Bioengineering Young Innovator Award, 2014
   - Ruth L. Kirschstein National Research Service Award, NIH/NIAID, 2008
   - NSF Young Scholar, US–China Forum on Science and Technology Policy, 2006
   - Christine Mirzayan Science and Technology Policy Fellow, U.S. Nat'l Academies, 2006
   - Claire Booth Luce Fellow, Thayer School of Engineering, Dartmouth College, 1997
   - Phi Beta Kappa, Dartmouth College, 1996

8. Service activities (within and outside Yale):

   Within Yale:
   - Member, Executive Committee for the Sackler / Integrated Graduate Program in Physical and Engineering Biology
   - Member of a variety of internal committees and university-wide committees

   Outside Yale:
   - Co-organizer of the inaugural Cold Spring Harbor Laboratories meeting on Systems Immunology, 2018

9. Most important publications and/or presentations (last five years):
   - V.C. Wong, M. Shibin, R. Ramji, S. Gaudet, and K. Miller-Jensen, "Fold-change

detection of NF-κB at targets with different transcript outputs," Biophysical Journal **116** (2019) 709–724.

- V.C. Wong, V.L. Bass, M.E. Bullock, A.K. Chavali, R.E.C. Lee, W. Mothes, S. Gaudet, and K. Miller-Jensen, "NF-κB-chromatin interactions drive diverse phenotypes by modulating transcriptional noise," Cell Reports **22** (2018) 585–599.
- R. Ramji, A.F. Alexander, A. Muñoz-Rojas, L.N. Kellman, and K. Miller-Jensen, "Microfluidic chip enables paired measurements of signaling and secretion in the same single cells," Integrative Biology **11** (2018) 142–153.
- C.J. Perry, A. Muñoz-Rojas, K.M. Meeth, L.N. Kellman, R.A. Amezquita, T. Durga, V.Y. Du, J.X. Wang, W. Damsky, J.W. Sher, C. Robles-Oteiza, M. Bosenberg, K. Miller-Jensen, and S.M. Kaech, "Combined CD40 agonist and CSF1R inhibitor treatment requires inflammatory cytokines to mediate an anti-tumor effect," J. Experimental Medicine **215** (2018) 877–893.
- L.E. Fong, E.S. Sulistijo, and K. Miller-Jensen, "Systems analysis of latent HIV reversal alters stress kinase signaling and increases cell death in infected T cells," Scientific Reports **7** (2017) 16179.
- S. Gaudet and K. Miller-Jensen, "Redefining signaling networks with an expanding single-cell toolbox," Trends in Biotechnology **34** (2016) 458–469.
- A.K. Chavali, V.C. Wong, and K. Miller-Jensen, "Distinct promoter activation mechanisms modulate noise-driven HIV gene expression," Scientific Reports **15** (2015) 17661.
- Q. Xue, Y. Lu, M.R. Eisele, E. Sulistijo, N.T. Khan, R. Fan, and K. Miller-Jensen, "Analysis of single-cell secretion reveals a role for paracrine signaling in coordinating macrophage response to TLR4 stimulation," Science Signaling **8** (2015) ra59.
- R. Ramji, V.C. Wong, A.K. Chavali, L. Gearhart, and K. Miller-Jensen, "A passive-flow microfluidic device for imaging latent HIV activation dynamics in single T cells," Integrative Biology **7** (2015) 998–1010.
- Y. Lu, Q. Xue, M.R. Eisele, E. Sulistijo, K. Brower, L. Han, E.D. Amir, D. Pe'er, K. Miller-Jensen, and R. Fan, "Highly multiplexed profiling of immune effector functions reveals deep functional heterogeneity in response to pathogenic ligands," Proc. Natl. Acad. Sci., U.S.A. **112** (2015) 607–615.

10. Professional development activities:
    - Developer and teacher of "Paper-based microfluidic devices for disease detection" class as part of the Pathways to Science Summer SCHOLAR Program, Yale University
    - Frequent reviewer for scientific journals
    - Attended the Summer Teaching Institute (learned techniques to incorporate active learning into STEM courses), Yale University, 2014

1. Name and academic rank: Michael Murrell
Associate Professor of Biomedical Engineering

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Bioengineering, Massachusetts Institute of Technology, 2009
   B.S. Biomedical Engineering, Johns Hopkins University, 2004

3. Academic experience with institution rank and title:
   - Associate Professor, Biomedical Engineering, Yale University, 2020–present
   - Assistant Professor, Biomedical Engineering, Yale University, 2015–2020
   - Assistant Professor, Biomedical Engineering, Univ. of Wisconsin, Madison, 2013–2015
   - Postdoctoral Associate, Physics, Univ. of Chicago and Institut Curie, France, 2009–2013

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Physical Society (APS), Biophysical Society (BPS)

7. Honors and awards:
   - Yale Arthur Greer Memorial Prize, 2020
   - Young Investigator Award, Human Frontiers of Science Program, 2018
   - Postdoctoral Fellowship, NSF Institute for Complex Adaptive Matter (ICAM), 2010–2013
   - NIH Biotechnology Training Grant/Fellowship, 2005–2008
   - Lemelson Fellowship/MIT Presidential Fellow, 2004–2005

8. Service activities (within and outside Yale):
   Within Yale:
   - Frequent member of a variety of internal committees
   - Member of multiple career panels to enhance the recruitment of URM students in STEM
   - Organizer/participant in various departmental recruiting events to increase the representation of URM students in STEM
   - Member, Executive Committee for the Sackler / Integrated Graduate Program in Physical and Engineering Biology

   Outside Yale:
   - Member of multiple career panels to enhance the recruitment of URM students in STEM

9. Most important publications and/or presentations (last five years):
   - V. Ajeti, A.P. Tabatabai, A.J. Fleszar, M.F. Staddon, D.S. Seara, C. Suarez, M.S. Yousafzai, D. Bi, D.R. Kovar, S. Banerjee, and M.P. Murrell, "Wound healing coordinates actin architectures to regulate mechanical work," Nat. Phys. **15** (2019) 696–705.
   - V. Yadav, D. Banerjee, A. Tabatabai, D. Kovar, T. Kim, S. Banerjee, and M. Murrell,

"Filament nucleation tunes mechanical memory in active polymer networks," Adv. Functional Materials **29** (2019) 1905243.

- X.F. Zhang, V. Ajeti, N. Tsai, A. Fereydooni, W. Burns, M. Murrell, E.M. De La Cruz, and P. Forscher, "Regulation of axon growth by myosin II-dependent mechanocatalysis of cofilin activity," J. Cell Biol. **218** (2019) 2329–2349.
- D.S. Seara, V. Yadav, I. Linsmeier, A.P. Tabatabai, P.W. Oakes, S.M.A. Tabei, S. Banerjee, and M.P. Murrell, "Entropy production rate is maximized in non-contractile actomyosin," Nat. Commun. **9** (2018) 4948.
- I. Linsmeier, S. Banerjee, P.W. Oakes, W. Jung, T. Kim, and M.P. Murrell, "Disordered actomyosin networks are sufficient to produce cooperative and telescopic contractility. Nat Commun. **7** (2016) 12615.
- M. Murrell, P.W. Oakes, M. Lenz, and M.L. Gardel, "Forcing cells into shape: The mechanics of actomyosin contractility," Nat. Rev. Mol. Cell Biol. **16** (2015) 486–498.
- M. Murrell, R. Voituriez, J.-F. Joanny, P. Nassoy, C. Sykes, and M.L. Gardel, "Liposome adhesion generates traction stress," Nature Physics **10** (2014) 163–169.
- M. Murrell and M.L. Gardel, "Actomyosin sliding is attenuated in contractile biomimetic cortices," Mol. Biol. Cell **25** (2014) 1845–1853.
- M. Murrell, T. Thoresen, and M. Gardel, "Reconstitution of contractile actomyosin arrays," Methods Enzymol. **540** (2014) 265–282.

10. Professional development activities:
    - Developed a new graduate course entitled, "Molecular and Cellular Biomechanics," which incorporates computational simulations run by students to general novel results, as well as the writing of scientific articles.
    - Developed a new undergraduate course entitled, "Introduction to Biomechanics," in which students learn a broad range of mechanics, from solid and fluid to statistical. Students apply what they learn with hands-on computational modules.
    - Reviewer for several scientific journals

1. Name and academic rank: Mark A. Reed
Harold Hodgkinson Professor of Engineering & Applied Science and Professor of Electrical Engineering and Applied Physics

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Physics, Syracuse University, 1983
   - M.S. Physics, Syracuse University, 1979
   - B.S. Physics, Syracuse, 1977

3. Academic experience with institution rank and title:
   - Associate Director, Yale Institute for Nanoscience and Quantum Engineering, 2007–2015
   - Harold Hodgkinson Professor of Eng. & Applied Science, Yale University, 1999–present
   - Professor of Electrical Engineering and Applied Physics, Yale University, 1990–present

4. Non-academic experience:
   - Senior Member of Technical Staff, Central Research Labs, Texas Instruments, 1983–1990

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Institute of Electrical and Electronics Engineers (IEEE), Fellow; American Physical Society (APS), Fellow; Connecticut Academy of Science and Engineering

7. Honors and awards:
   - Finalist, World Technology Award, 2010
   - IEEE Pioneer Award in Nanotechnology, 2007
   - Fellow, Canadian Institute for Advanced Research, 2006
   - Yale Science & Eng. Alumni Award for Advancement of Basic and Appl. Science, 2002
   - Fujitsu ISCS Quantum Device Award, 2001
   - Syracuse University Distinguished Alumni Award, 2000
   - DARPA ULTRA Most Significant Technical Achievement Award, 1997
   - Who's Who in the World, 2000–present; in America, 2000–present; and in American Science and Engineering, 1995–present)
   - Kilby Young Innovator Award, 1994
   - Fortune Magazine's 12 most promising young scientists, 1990

8. Service activities (within and outside Yale):
Within Yale:
   - Chair of Electrical Engineering, 1995–2001
   - Director of Undergraduate Studies for Elec. Eng., 2010–2011, 2012–2013, 2015–present

Outside Yale:
   - Editorships: Editor-in-Chief, Nano Futures, 2016–present; Editor, Proceedings of the IEEE, 2009–present; Editor-in-Chief, Nanotechnology, 2009–2019; Editor, IEEE

Transaction Electron Devices, 2005–2011; Divisional Associate Editor, Physical Review Letters, 1996–1999

- Editorial board member: Superlattices and Microstructures; Supermolecular Science and Technology; Small; Encyclopedia of Nanoscience and Nanotechnology
- Conference chair:
  - Gordon Conference on Nanostructure Fabrication, 2012 (Chair) and Vice-Chair (2010)
  - 27th International Symposium on Compound Semiconductors, 2001
  - Silicon Nanoelectronics Workshop, 1996
  - Ordered Molecular and Nanoscale Electronics, 1994; International Conference on Nanostructures and Mesoscopic Systems, 1991
  - International Conference on Nanostructure Physics and Fabrication, 1989
- Program Chair: 24th International Symposium on Compound Semiconductors, 1997
- Publications Chair: NANOMES, 1996
- Member of program committees for numerous national and international conferences
- Numerous NSF, DARPA, ONR, and government workshops
- Member, President's Council of Advisors on Science and Technology (PCAST)
- Adviser, International Technology Roadmap for Semiconductors (ITRS)
- Member of scientific advisory boards: Sandia/LANL Center for Integrated Nanotechnologies; UPenn NSF Nano/Bio Interface Center; Univ. of Copenhagen UNIK

9. Most important publications and/or presentations (last five years):

- T. Li, S.X. Li, W. Kong, C. Chen, E. Hitz, C. Jia, J. Dai, X. Zhang, R. Briber, Z. Siwy, M.A. Reed, and L. Hu, "A nanofluidic ion regulation membrane with aligned cellulose nanofibers," Science Advances **5** (2019) eaau4238.
- L. Mu, I.A. Droujinine, J. Lee, M. Wipf, P. Davis, C. Adams, J. Hannant, and M.A. Reed, "Nanoelectronic platform for ultrasensitive detection of protein biomarkers in serum using DNA amplification," Analytical Chemistry **89** (2017) 11325–11331.
- M.A. Reed, "Nanobioelectronic systems," Quindao Symposium, Quindao, China, 2016 (plenary talk).
- M.A. Reed, "More than Moore: When electronics drives off the roadmap," Kay Malmstrom Lecture in Physics, Hamline University, St. Paul, MN, 2015 (named lecture).
- S.X. Li, W. Guan, B. Weiner, and M.A. Reed, "Direct observation of charge inversion in divalent nanofluidic devices," Nano Lett. **15** (2015) 5046.
- M.A. Reed, "Molecular transistors," 7th International Conference on Molecular Electronics, Strasbourg, France, 2014 (plenary talk).
- M. Luye Mu, I.A. Droujinine, N.K. Rajan, S.D. Sawtelle, and M.A. Reed, "Direct, rapid, and label-free detection of enzyme−substrate interactions in physiological buffers using CMOS-compatible nanoribbon sensors," NanoLett. **14** (2014) 5315.
- H. Song, T. Lee, and M.A. Reed, "Inelastic electron tunneling spectroscopy of molecular transport junctions," J. Korean Phys. Soc. **64** (2014) 1539.

10. Professional development activities:

- Research: Thrust co-leader in a DOE Energy Research Frontier Center
- Conferences: Developing new areas, attended Asilomar Bioelectronics 2019
- Duties: Increasing effectiveness and resources of the EE DUS position

1. Name and academic rank: Holly Rushmeier
John C. Malone Professor of Computer Science

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Mechanical Engineering, Cornell University, 1988
M.S.	Mechanical Engineering, Cornell University, 1986
B.S.	Mechanical Engineering, Cornell University, 1977

3. Academic experience with institution rank and title:
   - John C. Malone Professor, Computer Science, Yale University, 2019–present
   - Professor, Computer Science, Yale University, 2004–2019
   - Assistant Professor, Mechanical Engineering, Georgia Institute of Technology, 1988–1991

4. Non-academic experience:
   - Research Staff Member, IBM Thomas J. Watson Research Center, 1996–2004
   - Computer Scientist, National Institute of Standards and Technology, 1991–1996
   - Engineer, Washington Natural Gas Company, 1980–1983
   - Engineer, Boeing Commercial Airplane Company, 1977–1979

5. Certifications or professional registrations: Professional Engineer, State of WA

6. Current membership in professional organizations: Fellow and Distinguished Engineer of the Association for Computing Machinery (ACM), Fellow of the Eurographics Association, Connecticut Academy of Science and Engineering

7. Honors and awards:
   - ACM SIGGRAPH Academy, 2018
   - ACM SIGGRAPH Computer Graphics Achievement Award, 2013
   - Presidential Young Investigator, National Science Foundation, 1990

8. Service activities (within and outside Yale):

   Within Yale:
   - Chair, Computer Science, 2011–2014
   - Frequent member of a variety of departmental and university-wide committees

   Outside Yale:
   - Editorships:
     - Current member of editorial boards for ACM Transactions on Applied Perception, Computational Visual Media, The Visual Computer, and Computers & Graphics
     - Associate Editor-in-Chief, IEEE Computer Graphics and Applications
     - Co-Editor-in-Chief, Computer Graphics Forum, 2010–2014
     - Editor, IEEE Transactions on Visualization and Computer Graphics, 1996–1998
     - Editor-in-Chief, ACM Transactions on Graphics, 1996–1999
   - Papers (co-)chair:

- Papers co-chair, Eurographics Rendering Conference, 2000
  - Papers co-chair, IEEE Visualization Conference, 1998, 2004, 2005
  - Papers chair, ACM SIGGRAPH Conference, 1996
- Workshop (co-)organizer:
  - Co-organizer, Eurographics Workshop on Material Appearance Modeling, 2013–2020
  - Co-organizer, CRA-W (Computer Research Association - Women) Career Mentoring Workshops 2012, 2015, 2016, 2018
  - Org., CRA CCC Workshop on "Content Authoring for Workforce Training," 2019,
  - Org., ACM SIGGRAPH Workshop on "Content Auth. for Workforce Training," 2019

9. Most important publications and/or presentations (last five years):
   - Y. Hu, J. Dorsey, and H. Rushmeier, "A novel framework For inverse procedural texture modeling," ACM Transactions on Graphics **38** (2019) 186.
   - Z. Wang, S. Qiu, Q. Chen, N. Trayan, A. Ringlein, J. Dorsey, and H. Rushmeier, "AniCode: Authoring coded artifacts for network-free personalized animations," The Visual Computer **35** (2019) 885–897.
   - Z. Wang, W. Shi, K. Akoglu, E. Kotoula, Y. Yang, and H. Rushmeier, "CHER-Ob: A tool for shared analysis and video dissemination," ACM J. Computing and Cultural Heritage **11** (2018) 18.
   - M. Lau, K. Dev, J. Dorsey, and H. Rushmeier, "A human-perceived softness measure of virtual 3D objects," ACM Transactions on Applied Perception (TAP) **15** (2018) 19.
   - J. Filip, M. Kolafová, M. Havlíček, R. Vávra, M. Haindl, and H. Rushmeier, "Evaluating physical and rendered material appearance," The Visual Computer **34** (2018) 805–816.
   - Y. Yang, R. Pintus, H. Rushmeier, and I. Ivrissimtzis, "A 3D steganalytic algorithm and steganalysis-resistant watermarking," IEEE Trans. Vis. Comput. Graph. **23** (2017) 1002–1013.
   - Y.D. Lockerman, B. Sauvage, R. Allègre, J.M. Dischler, J. Dorsey, and H. Rushmeier, "Multi-scale label-map extraction for texture synthesis," ACM Transactions on Graphics **35** (2016) 140.
   - R. Pintus, K. Pal, Y. Yang, T. Weyrich, E. Gobbetti, and H. Rushmeier, "A survey of geometric analysis in cultural heritage," Computer Graphics Forum **35** (2016) 4–31.
   - M. Lau, K. Dev, W. Shi, J. Dorsey, and H. Rushmeier, "Tactile mesh saliency," ACM Transactions on Graphics **35** (2016) 52.
   - R. Pintus, Y. Yang, and H. Rushmeier, "ATHENA: Automatic text height extraction for the analysis of text lines in old handwritten manuscripts," J. Comput. Cult. Herit. **8** (2015) 25.

10. Professional development activities:
    - Frequent reviewer for scientific journals
    - Keynote speaker at several national and international conferences

1. Name and academic rank: W. Mark Saltzman
Goizueta Foundation Professor of Biomedical and Chemical Engineering, Professor of Cellular & Molecular Physiology, and Professor of Dermatology

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Medical Engineering, Massachusetts Institute of Technology, 1987
   S.M. Chemical Engineering, Massachusetts Institute of Techhnology, 1984
   B.S. Chemical Engineering, Iowa State University, 1981

3. Academic experience with institution rank and title:
   - Professor, Dermatology, Yale University, 2018–present
   - Professor, Cellular & Molecular Physiology, Yale University, 2004–present
   - Goizueta Foundation Professor, Biomedical and Chemical Eng., Yale Univ., 2002–present
   - B.P. Amoco/H. Laurance Fuller Professor, Chemical Eng., Cornell Univ., 1996–2002
   - Professor, Chemical Engineering, The Johns Hopkins University, 1995–1996
   - Associate Professor, Chemical Engineering, The Johns Hopkins University, 1992–1994
   - Assistant Professor, Chemical Engineering, The Johns Hopkins University, 1987–1992
   - Postdoctoral Researcher, Biological Sci., Massachusetts Inst. of Technology, 1984–1987

4. Non-academic experience:
   - 15 patents issued

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the Biomedical Engineering Society (BMES), Fellow of the American Institute of Medical and Biological Engineering (AIMBE), Connecticut Academy of Science and Engineering, American Institute of Chemical Engineers (AIChE), American Chemical Society (ACS), American Association for the Advancement of Sciences (AAAS), Controlled Release Society

7. Honors and awards:
   - Elected Member, National Academy of Engineering, 2018
   - Founders Award, Controlled Release Society, 2017
   - Elected Member, National Academy of Medicine (formerly Institute of Medicine), 2014
   - Mines Medalist, South Dakota School of Mines, 2014
   - Fellow, Brain Research Foundation, 2014
   - Fellow, National Academy of Inventors, 2013
   - Professional Achievement Citation in Engineering Award, Iowa State University, 2013
   - Sheffield Teaching Prize, Yale University, 2009
   - Paper selected as one of top 25 published over past 25 years in Biomaterials, 2006
   - Distinguished Lecturer Award, Biomedical Engineering Society, 2004
   - Jorge Heller Journal of Controlled Release Outstanding Paper Award, 2001

- NYSTAR Award, Faculty Development Program, 2001
- Professional Progress in Engineering Award, Iowa State University, 2000
- Richard Tucker Excellence in Teaching Award, Cornell University, 1999
- Controlled Release Society Young Investigator Award, 1996
- Allan C. Davis Medal, Maryland's Outstanding Young Engineer Award, 1995
- Distinguished Faculty Award, The Johns Hopkins University, 1995
- Camille and Henry Dreyfus Foundation Teacher-Scholar Award, 1990
- Numerous named lectureships, both nationally and internationally

8. Service activities (within and outside Yale):

Within Yale:

- Head of College, Jonathan Edwards College, 2016–present
- Co-founder, Center for Biomedical and Innovative Technology (CBIT), 2014–present
- Founding Chair of Biomedical Engineering, 2003–2015
- Member of numerous internal and university-wide committees

Outside Yale:

- Series Editor, Cambridge University Press Texts in Biomedical Engineering, 2005–present
- Current Editorial Board Member of Bioeng. Transl. Med., Molec. Therapy: Methods and Clin. Dev., J. Ocul. Biol. Dis. Infor., J. Controlled Release, and Biomaterials
- Member of scientific advisory boards: Stradefy Biosciences, 2019–present; Nanosive S.AS., 2018–present; Trucode Gene Repair, 2017–present; 480 Biomedical/Arsenal Medical, 2010–2016; Genentech, 2010–2014; Carigent, 2006–2009; Gamma-A, 1999–2000; and UltraFem, Inc., 1992–1998
- Member of over 15 government and university advisory panels over the past 30 years
- (Co-)organizer or (co-)chair of approximately 20 symposia and annual meetings

9. Most important publications and/or presentations (last five years):

- A.S. Ricciardi, R. Bahal, J.S. Farrelly, E. Quijano, A.H. Bianchi, V.L. Luks, R. Putman, F. Lopez-Giraldez, S. Coskun, E. Song, Y. Liu, W.C. Hsieh, D.H. Ly, D.H. Stitelman, P.M. Glazer, and W.M. Saltzman, "In utero nanoparticle delivery for site-specific genome editing," Nature Communications **9** (2018) 2481.
- G.T. Tietjen, S.A. Hosgood, N.C. Kirkiles-Smith, J. Cui, A.S. Piotrowski-Daspit, D. Deep, E. Song, R. Al-Lamki, J.A. Bradley, K. Saeb-Parsy, J.R. Bradley, M.L. Nicholson, W.M. Saltzman, and J.S. Pober, "Antibody-targeting can increase nanoparticle delivery to endothelial cells during ex vivo normothermic machine perfusion of human kidney," Science Translational Medicine **9** (2017) eaam6764.
- Y. Deng, A. Ediriwickrema, F. Yang, J. Lewis, M. Girardi, and W.M. Saltzman, "A sunblock based on bioadhesive nanoparticles," Nature Materials **14** (2015) 1278–1285 (2015).
- Biomedical Engineering: Bridging Medicine and Technology, 2nd ed., by W.M. Saltzman, Cambridge University Press (2015).

10. Professional development activities:

- Led a 13-week seminar at Yale Nat'l Initiative (for public school teachers), 2006–2017
- Frequent attendee at conferences, both nationally and internationally

1. Name and academic rank: Brian M. Scassellati
A. Bartlett Giamatti Professor of Computer Science and Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Computer Science, Massachusetts Institute of Technology, 2001
M.Eng. Computer Science and Electrical Engineering, Massachusetts Institute of Technology, 1995
B.S. Computer Science and Brain & Cognitive Science, Massachusetts Institute of Technology, 1995

3. Academic experience with institution rank and title:
- A Bartlett Giamatti Professor, Computer Science and Mechanical Engineering & Materials Science, Yale University, 2019–present
- Professor, Computer Science, Yale University, 2013–2019
- Associate Professor, Computer Science, Yale University, 2006–2013
- Assistant Professor, Computer Science, Yale University, 2001–2006
- Postdoctoral Associate, Artificial Intelligence Laboratory, Massachusetts Institute of Technology, 2001

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Cognitive Science Society (CSS), Institute for Electrical and Electronics Engineers (IEEE)

7. Honors and awards:
- Dylan Hixon ’88 Prize for Teaching Excellence in the Natural Sciences, Yale Univ., 2020
- AAAS Leshner Leadership Fellow for Public Engagement with Science, 2020
- Yale Science & Engineering Association Award for Meritorious Service, 2019
- Higher Level Cognition Modeling Prize, Cognitive Science Conference, 2009
- Alfred P. Sloan Research Fellowship, 2007
- A. Richard Newton Breakthrough Research Award, Microsoft, 2008
- Best Paper Award, 6th International Conference on Development and Learning, 2006
- Best Applied Computational Modeling Paper, 28th Annual Meeting of the CSS, 2006
- Best Paper Award, 3rd International Conference on Development and Learning, 2004
- NSF CAREER Award, 2003
- Best Paper Award, 1st International IEEE/RSJ Conference on Humanoid Robotics, 2000
- National Defense Science and Engineering Graduate (NDSEG) Fellowship, 1995–1998

8. Service activities (within and outside Yale):
Within Yale:

- Acting Chair, Cognitive Science Program, 2011
- Member of a variety of departmental and university-wide committees (e.g., Advancement Cmte. for Eng., Graduate School of Arts and Sciences Exec. Cmte., Advisory Board of the Franke Program in Science and the Humanities, Physical Sciences Tenure and Promotions Cmte., Exec. Cmte. of the Cognitive Science Program, Scholar Awards Cmte., etc.)

Outside Yale:

- Councilor, American Association for Artificial Intelligence (elected member of governing board) and Chair of AAAI External Communications Cmte., 2019–2022
- Conference or workshop (co-)organizer:
  - AI-HRI AAAI Fall Symposium Series, 2015
  - Robotics Systems and Science Workshop on Human-Robot Interaction, 2015
  - ACM/IEEE Int'l Conference on Human-Robot Interaction, 2012–2014
  - US/Japan workshops on Telepresence and Human-Robot Interaction, 2010
  - ICRA Workshop on Unifying Characteristics of Research in Human-Robot Interaction, 2008
  - ACM/IEEE Int'l Conference on Human-Robot Interaction, "The Future of HRI," 2007
  - IEEE World Congress on Comput. Intell., "Autonomous Mental Development," 2006
- Guest Editor, inaugural issue of J. Human-Robot Interaction, 2011
- Co-Guest Editor, special issue of Int. J. Humanoid Robotics, 2007
- Panelist at several workshops

9. Most important publications and/or presentations (last five years):
   - M.L. Traeger, S.S. Sebo, M. Jung, B. Scassellati, B., and N.A. Christakis, "Vulnerable robots positively shape human conversational dynamics in a human–robot team," PNAS **117** (2020) 6370-6375.
   - A. Ramachandran, C.M. Huang, and B. Scassellati, "Toward effective robot–child tutoring: Internal motivation, behavioral intervention, and learning outcomes," ACM Trans. Interactive Intelligent Systems **9** (2019) 1–23.
   - D. Leyzberg, A. Ramachandran, and B. Scassellati, "The effect of personalization in longer-term robot tutoring," ACM Trans. Human-Robot Interaction **7** (2018) 19.
   - B. Scassellati, L. Boccanfuso, C.M. Huang, M. Mademtzi, M. Qin, N. Salomons, and F. Shic, "Improving social skills in children with ASD using a long-term, in-home social robot," Science Robotics **3** (2018) eaat7544.
   - T. Belpaeme, J. Kennedy, A. Ramachandran, B. Scassellati, and F. Tanaka, "Social robots for education: A review," Science Robotics **3** (2018) eaat5954.
   - I. Leite, M. McCoy, M. Lohani, D. Ullman, N. Salamons, C. Stokes, S. Rivers, and B. Scassellati, "Affective narratives with robots: The impact of interaction context and individual differences on story recall and emotional understanding," Frontiers in Robotics and Artificial Intelligence **4** (2017) 29.

10. Professional development activities:
    - Frequent reviewer for scientific journals
    - Keynote speaker at several national and international conferences
    - Speaker at public venues (New Canaan Public Library, Branford Public Library, etc.)

1. Name and academic rank: T. Kyle Vanderlick
Dean Emeritus, School of Engineering & Applied Science,
Thomas E. Golden Professor of Engineering

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Chemical Engineering, University of Minnesota, 1988
   - M.S. Chemical Engineering, Rensselaer Polytechnic Institute, 1983
   - B.S. Chemical Engineering, Rensselaer Polytechnic Institute, 1981

3. Academic experience with institution rank and title:
   - Thomas E. Golden Professor, Engineering, 2008–present
   - Dean, School of Engineering & Applied Science, Yale University, 2008–2017
   - Associate Dean for Academic Affairs, School of Engineering & Applied Sciences, Princeton University, 2003–2004
   - Professor, Chemical Engineering, Princeton University, 1998–2007
   - Associate Professor, Chemical Engineering, University of Pennsylvania, 1995–1998
   - Assistant Professor, Chemical Engineering, University of Pennsylvania, 1989–1995

4. Non-academic experience:
   - Visiting Scientist, Complex Fluids Laboratory, Rhone-Poulenc, 1997
   - NATO Postdoctoral Fellow, Universität Mainz, West Germany, 1988–1989
   - Industrial Trainee Fellow, Proctor & Gamble, 1981

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Institute of Chemical Engineers (AIChE), American Physical Society (APS)

7. Honors and awards:
   - John Quinn Lecturer, University of Pennsylvania, Dept. of Chemical Engineering, 2010
   - Ethel Z. Casassa Memorial Lecturer, Carnegie Mellon, Dept. of Chemical Engineering, 2006
   - Grace Hopper Lecturer, University of Pennsylvania, Dept. of Chemical Engineering, 2002
   - President's Award for Distinguished Teaching, Princeton University, 2002
   - Princeton Engineering Council Teaching Award, 2002
   - Van Ness Lecturer, Rensselaer Polytechnic Institute, Dept. of Chemical Engineering, 1997
   - Philip's Lecturer, Haverford College, Dept. of Physics, 1996
   - Class of 1942 Endowed Term Chair, University of Pennsylvania, 1995
   - S. Reid Warren, Jr. Award for Distinguished Teaching, 1994
   - Christian R. and Mary F. Lindback Foundation Award for Excellence in Teaching, 1993
   - David and Lucile Packard Fellowship, 1991
   - Presidential Young Investigator Award, 1989
   - NATO Postdoctoral Fellowship in Science and Engineering, 1988–1989

8. Service activities (within and outside Yale):

Outside Yale:

- External reviewer for various programs:
  - Schmidt Science Fellows Program, 2019–2020
  - Dept. of Chemical and Biomolecular Engineering, UC Berkeley, 2013
  - Thayer School of Engineering, Dartmouth College, 2012
  - School of Chemical and Biomolecular Engineering, Cornell University, 2012
  - Dept. of Chemical Engineering, University of Buffalo, 2008
  - Dept. of Chemical Engineering, UC Santa Barbara, 2008
  - School of Chemical Engineering, Purdue University, 2007
  - School of Chemical and Biomolecular Eng., Cornell University, 2003
- Advisory Council, Dept. of Chemical Engineering, University of Delaware, 2007–2012
- Visiting Committee, Dept. of Chemical and Biomolecular Engineering, Johns Hopkins, 2007–2011
- Technical Advisory Panel, HelioVolt Corporation, 2006
- Chair of Chemical Engineering, Princeton University, 1994–2000

9. Most important publications and/or presentations (last five years):

- F. Carle, K. Bai, T.K. Vanderlick, and E. Brown, "Development of magnetic liquid metal suspensions for magnetohydrodynamics," Phys. Rev. Fluids **2** (2017) 1–20.
- N. Dogra, H. Izadi, and T.K. Vanderlick, "A motile bacteria-based system for liposome cargo," Nature Scientific Reports **6** (2016) 1–9.
- H. Izadi, H. Dogra, F. Perreault, C. Schwarz, S. Simon, and T.K. Vanderlick, "Removal of particulate contamination from solid surfaces using polymeric micropillars," Applied Materials and Interfaces **8** (2016) 16967–16978.

10. Professional development activities: N/A

1. Name and academic rank: John S. Wettlaufer
A.M. Bateman Professor of Geophysics, Physics, and Mathematics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Physics and Mathematics, University of Washington, 1991
B.S. Physics and Mathematics, University of Puget Sound, 1985

3. Academic experience with institution rank and title:
- Visiting Professor, Applicable Mathematics, University of Oxford, 2014–present
- Guest Professor, Applied Mathematics and Theoretical Physics, Nordic Institute for Theoretical Physics (NORDITA), 2014–present
- Statutory Professor, Applicable Mathematics, University of Oxford, 2013–2014
- Tage Erlander Professor, Theoretical Physics, NORDITA, 2012
- A.M. Bateman Professor, Geophysics, Physics, & Mathematics, Yale Univ., 2008–present
- Professor, Geophysics and Physics, Yale University, 2002–2008
- Assistant to Full Affiliate Professor, Physics, University of Washington, 1995–present
- Physicist to Senior Physicist, Appl. Physics Laboratory, Univ. of Washington, 1993–2002

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Fellow of the American Physical Society (APS), Fellow of the American Geophysical Union (AGU), Royal Swedish Academy of Sciences

7. Honors and awards:
- John Carlson Lecturer, Lorenz Center, Massachusetts Institute of Technology, 2013
- Wolfson Merit Award, Royal Society of London, 2013
- Guggenheim Fellow, 2010–2011
- Oxford Visiting Fellow, Mathematical Institute, Oxford University, 2010
- Wenner-Gren Foundation Fellow, Stockholm, 2008
- Houghton Lecturer, Massachusetts Institute of Technology, 2007
- Visiting Fellow Commoner, Trinity College, Cambridge, 2005

8. Service activities (within and outside Yale):
Within Yale:
- Director of Undergraduate Studies for Applied Mathematics, 2017–present
- Director of Graduate Studies for Geology & Geophysics, 2006–2009
- Member of many internal committees, both department-specific and university-wide (e.g., Physical Sciences Advisory Council, Tenure and Appts. Committee, Committee on Honors & Academic Standing, Graduate Admissions, Committee on Teaching Fellows, Graduate Curriculum Committee, and departmental search committees)

Outside Yale:

- Director, Geophysical Fluid Dynamics Summer Program on Stochastic Processes, Woods Hole Oceanographic Institute, 2015
- Member of various committees at Brookhaven National Laboratory:
  - Instrumentation Division Review Committee, 2015
  - Advisory Committee, Environmental, Biological, and Computational Sciences Directorate, 2013
  - Science & Technology Steering Committee, 2010–present
- Officer of the Inaugural Executive Committee of the APS's Topical Group on the Physics of Climate: Vice Chair, 2013; Chair-Elect, 2014; Chair, 2015; Past Chair, 2016
- Member of various committees at University of Oxford:
  - Jesus College Junior Research Fellowship Competition, Mathematics, 2014
  - Faculty Board, Oxford Centre for Collaborative Applied Mathematics, 2013–2014
  - Mathematical Methods Subject Panel
  - Mathematics Part B Examiners, Structured Projects Assessor
  - Mathematics Part C Examiners, Dissertation Adviser
- Founding Director, Mathematical Observatory, University of Oxford
- Associate Editor, J. Fluid Mechanics, 2009–present

9. Most important publications and/or presentations (last five years):

- S. Pramanik and J.S. Wettlaufer, "Confinement effects in premelting dynamics," Phys. Rev. E **96** (2017) 052801.
- F. Mancarella and J.S. Wettlaufer, "Surface tension and a self-consistent theory of composite solids with elastic inclusions," Soft Matter **13** (2017) 945.
- S. Toppaladoddi, S. Succi and J.S. Wettlaufer, "Roughness as a route to the ultimate regime of thermal convection," Phys. Rev. Lett. **118** (2017) 074503.
- F. Guarnieri, W. Moon, and J.S. Wettlaufer, "Solution of the Fokker-Planck equation with a logarithmic potential and mixed eigenvalue spectrum," J. Math. Phys. **58** (2017) 093301.
- W. Moon and J.S. Wettlaufer, "A stochastic dynamical model of Arctic sea ice*," J. Clim.* **30** (2017) 5119.
- F. Mancarella, R.W. Style, and J.S. Wettlaufer, "Surface tension and the Mori-Tanaka theory of non-dilute soft composite solids," Proc. R. Soc. A **242** (2016) 20150853.
- C.W. MacMinn, E.R. Dufresne, and J.S. Wettlaufer, "Large deformations of a soft porous material," Phys. Rev. Applied **5** (2016) 044020.
- J.M.H. Schollick, R.W. Style, A. Curran, J. S. Wettlaufer, E.R. Dufresne, P.B. Warren, K.P. Velikov, R.P.A. Dullens, and D.G.A.L. Aarts, "Segregated ice growth in a suspension of colloidal particles," J. Phys. Chem. B **120** (2016) 3941–3949.
- C.W. MacMinn, E.R. Dufresne, and J.S. Wettlaufer, "Fluid-driven deformation of a soft granular material," Phys. Rev. X **5** (2015) 011020.
- R.W. Style, R. Boltyanskiy, B. Allen, K.E. Jensen, H.P. Foote, J.S. Wettlaufer, and E.R. Dufresne, "Stiffening solids with liquid inclusions," Nature Phys. **11** (2015) 82–87.

10. Professional development activities:

- Frequent reviewer for scientific journals

1. Name and academic rank: Daniel Wiznia,
Assistant Professor, Orthopaedics & Rehabilitation and
Mechanical Engineering & Materials Science

2. Degrees with disciplines, institutions, and dates:

Orthopaedic Surgery	Yale-New Haven Hospital
M.D.	Weill Cornell Medical College, 2012
B.S.	Mechanical Engineering, Yale University, 2006

3. Academic experience with institution rank and title: Unless otherwise specified, all appointments are in Mechanical Engineering & Materials Science (MEMS), Yale University.
   - Assistant Professor, Orthopaedics & Rehabilitation and MEMS, Yale Univ., 2019–present
   - Assistant Professor, Orthopaedics & Rehabilitation, Yale University, 2018–2019

4. Non-academic experience:
   - Business analyst, McKinsey & Company

5. Certifications or professional registrations: Medical license, States of CT and NY

6. Current membership in professional organizations: American Association of Hip and Knee Surgeons (AAHKS): Arthroplasty Surgeon in Training, 2017–present; New England Orthopedic Society (NEOS), Fellow member, 2017–present; American Orthopaedic Association (AOA): "Own the Bone" Publications Taskforce, 2017–present, and AOA Emerging Leaders Program, 2016–present; American Academy of Orthopaedic Surgeons (AAOS): Resident and fellow member, 2016–2017; Connecticut Orthopaedic Society (COS): Resident board member, 2015–2017, and Resident member, 2012–present; American Medical Association (AMA): Member, 2004–present; American Society of Mechanical Engineers (ASME): Member, 2004-present; Society of Automotive Engineers (SAE): Member, 2004–present

7. Honors and awards:
   - Grand Rounds to Yale University, Department of Internal Medicine, Section of Geriatrics
   - "Conservative and Surgical Management of Hip and Knee Osteoarthritis," 2019
   - Finalist and team leader, medical device category, Hack the OR, Yale School of Medicine, 2018
   - AOA Resident Leadership Forum Nominee, 2015
   - COS Resident Paper Award, 2015
   - AAOS/OREF/ORS Clinician Scholar Career Development Program, 2015

8. Service activities (within and outside Yale):

Within Yale:
   - First-year faculty adviser, 2018–present
   - Fellow, Silliman College, Yale University, 2018–present

9. Most important publications and/or presentations (last five years):

- N. Eftekhary, N. Shepard, D.H. Wiznia, R. Iorio, W.J. Long, and J. Vigdorchik, "Metal hypersensitivity in total joint arthroplasty," JBJS Reviews **6** (2018) e1. PMID 30516716.
- D.H. Wiznia, M. Wang, C.Y. Kim, and M.P. Leslie, "The effect of insurance type on patient access to ankle fracture care under the Affordable Care Act," Am. J. Orthop. (Belle Mead NJ) **47** (2018). PMID 30296321.
- D.H. Wiznia, T. Zaki, M.P. Leslie, and T.M. Halaszynski, "Complexities of perioperative pain management in orthopedic trauma," Cur. Pain Headache Rep. **22** (2018) 58. PMID 29987515.
- M. Adrados, D.H. Wiznia, M. Golden, and R. Pelker, "Lyme periprosthetic joint infection in total knee arthroplasty," Arthroplasty Today 4 (2018) 158–161. PMID 29896545.
- A.M. Samuel, P.J. Diaz-Collado, L.K. Szolomayer, D.H. Wiznia, W.W. Chan, A.M. Lukasiewicz, B.A. Basques, D.D. Bohl, and J.N. Grauer, "Incidence of and risk factors for knee collateral ligament injuries with proximal tibia fractures: A study of 32,441 patients," Orthopedics **41** (2018) e268–e276. PMID 29451942.
- D.H. Wiznia, E. Nwachuku, and R. Pelker, "The influence of medical insurance on patient access to orthopaedic surgery sports medicine appointments under the Affordable Care Act," Orthop. J. Sports Med. **5** (2017). PMID 28812034.

10. Professional development activities:

- "Movement is Life" Healthcare Disparities Steering Committee Member
- Yale-New Haven Hospital Hip Fracture Steering Committee Member

1. Name and academic rank: Fengnian Xia
Associate Professor of Electrical Engineering and Applied Physics

2. Degrees with disciplines, institutions, and dates:
   - Ph.D. Electrical Engineering, Princeton University, 2005
   - M.A. Electrical Engineering, Princeton University, 2001
   - B.E. Electronic Engineering, Tsinghua University, China, 1998

3. Academic experience with institution rank and title:
   - Barton L. Weller Associate Professor, Eng. & Applied Science, Yale Univ., 2019–present
   - Associate Professor, Electrical Engineering, Yale University, 2015–2019
   - Assistant Professor, Electrical Engineering, Yale University, 2013–2015

4. Non-academic experience:
   - Research Staff Member, IBM Research, 2009–2013
   - Optoelectronic Engineer, IBM Research, 2007–2009
   - Postdoctoral Researcher, IBM Research, 2005–2007
   - Co-inventor, 14 patents

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Institute of Electrical and Electronics Engineers (IEEE)

7. Honors and awards:
   - Presidential Early Career Award for Scientists and Engineers (PECASE), 2019
   - Highly Cited Research, Clarivate Analytics, 2017–2019
   - NSF CAREER Award, 2016
   - Office of Naval Research Young Investigator Program Awardee, 2015
   - IBM Corporate Award (highest award that IBM grants to its employees), 2012
   - TF35, MIT Technology Review's Top Young Innovators Under 35, 2011
   - Graduated with Highest Honors, Tsinghua University, 1998

8. Service activities (within and outside Yale):

   Within Yale:
   - Member of various internal committees

   Outside Yale:
   - Editorial board member: Nano Research, Advanced Optical Materials, 2D Materials, npj 2D Materials and Applications
   - Primary guest editor, IEEE J. of Selected Topics in Quantum Electronics, 2016
   - Host and organizer:
     - OSA Incubator Meeting, "Nanophotonic Devices: Beyond Classical Limits," 2014

- PIERS Session, “Electronics and Optoelectronics using Two-Dimensional Materials and their Heterostructures,” 2014
- IEEE Summer Topicals Meeting, “Functional Meta and 2D Materials” session, 2014

9. Most important publications and/or presentations (last five years):
   - C. Chen, X. Lu, B. Deng, X. Chen, Q. Guo, C. Li, C. Ma, S. Yuan, E. Sung, K. Watanabe, T. Taniguchi, L. Yang, and F. Xia, “Widely tunable mid-infrared light emission in thinfilm black phosphorus,” Science Advances **6** (2020) eaay6134.
   - C. Chen, F. Chen, X. Chen, B. Deng, B. Eng, D. Jung, Q. Guo, S. Yuan, K. Watanabe, T. Taniguchi, M. Lee, and F. Xia, “Bright mid-infrared photoluminescence from thin-film black phosphorus,” Nano Letters **19** (2019) 1488–1493.
   - Z.M.A. El-Fattah, V. Mkhitaryan, J. Brede, L. Fernandez, C. Li, Q. Guo, A. Ghosh, A.R. Echarri, D. Naveh, F. Xia, J.E. Ortega, and F.J. García de Abajo, “Plasmonics in atomically thin crystalline silver films,” ACS Nano **13** (2019) 7771–7779.
   - A. Levi, M. Kirshner, O. Sinai, E. Peretz, O. Meshulam, A. Ghosh, N. Gotlib, C. Stern, S. Yuan, F. Xia, and D. Naveh, “Graphene Schottky varactor diodes for high-performance photodetection,” ACS Photonics **6** (2019) 1910-1915.
   - X. Chen, Z. Zhou, B. Deng, Z. Wu, F. Xia, Y. Cao, L. Zhang, W. Huang, N. Wang, L. Wang, “Electrically tunable physical properties of two-dimensional materials,” Nano Today **27** (2019) 99–119.
   - F. Xia, H. Wang, J.C.M. Hwang, A.H. Castro Neto, and L. Yang, “Black phosphorus and its isoelectronic materials,” Nature Reviews Physics **1** (2019) 306–317.
   - C. Chen, X. Chen, H. Yu, Y. Shao, Q. Guo, B. Deng, S. Lee, C. Ma, K. Watanabe, T. Taniguchi, J.-G. Park, S. Huang, W. Yao, and F. Xia, “Symmetry-controlled electron-phonon Interactions in van der Waals heterostructures,” ACS Nano **13** (2018) 552–559.
   - Q. Guo, R. Yu, C. Li, S. Yuan, B. Deng, F. García de Abajo, and F. Xia, “Efficient electrical detection of mid-infrared graphene plasmons at room temperature,” Nature Materials **17** (2018) 986–992.
   - B. Deng, V. Tran, Y. Xie, H. Jiang, C. Li, Q. Guo, X. Wang, H. Tian, S. Koester, H. Wang, J. Cha, Q. Xia, L. Yang, and F. Xia, “Efficient electrical control of thin-film black phosphorus bandgap,” Nature Communications **8** (2017) 14474.
   - X. Chen, X. Lu, B. Deng, O. Sinai, Y. Shao, C. Li, S. Yuan, V. Tran, K. Watanabe, T. Taniguchi, D. Naveh, L. Yang, and F. Xia, “Widely tunable black phosphorus mid-infrared photodetector,” Nature Communications **8** (2017) 1672.
   - X. Ling, H. Wang, S. Huang, F. Xia, and M. Dresselhaus, “The renaissance of black phosphorus,” PNAS **112** (2015) 4523–4530.

10. Professional development activities:
    - Frequent reviewer for scientific journals: Science, Science Advances, Nature, Nature Nanotechnology, Nature Physics, Nature Photonics, Nature Materials, Nature Communications, ACS Nano, Nano Letters, J. Amer. Chemical Soc., Phys. Rev. Lett., Phys. Rev. X, Applied Physics Letters, AIP Advance, Advanced Materials, Optics Letters, Optics Express, and several IEEE journals
    - Grant reviewer for NSF, DOE, AFOSR, ARO, and a whole set of international science foundations (Israel, Netherlands, Canada, Singapore, Hong Kong, etc.)

1. Name and academic rank: Aaron Calderon
Instructor of Mathematics

2. Degrees with disciplines, institutions, and dates:

Ph.D. candidate	Mathematics, Yale University, 2016–present
M.S./M.Phil.	Mathematics, Yale University, 2020
B.S.	Mathematics, The University of Nebraska–Lincoln, 2016

3. Academic experience with institution rank and title:
    - Instructor, Mathematics, Yale University, 2016–present

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
    - NSF Graduate Research Fellowship, 2016–2022
    - Barry Goldwater Scholar, 2015
    - Dean H. and Floreen G. Eastman Scholarship

8. Service activities (within and outside Yale):

   Within Yale:
    - Graduate student mentor, SUMRY, Yale University, 2018, 2019
    - Mentor, Mathematics Directed Reading Program, Yale University, 2018–2019
    - Co-organizer, Mathematics Graduate Student Seminar Series, Yale University, 2017

   Outside Yale:
    - Invited graduate student, CeSMUR Conference, University of Nebraska–Lincoln, 2018
    - Student representative, Academic Program Review Committee, Univ. of Nebraska–Lincoln, 2015

9. Most important publications and/or presentations (last five years):
    - A. Calderon and N. Salter, "Framed mapping class groups and the monodromy of strata of Abelian differentials," (2020) submitted. arXiv:2002.02472.
    - A. Calderon and N. Salter, "Relative homological representations of framed mapping class groups," (2020) submitted. arXiv:2002.02471.
    - C. Adams, A. Calderon, and N. Mayer, "Generalized bipyramids and hyperbolic volumes of alternating k–uniform tiling links," Topology Appl. **271** (2020) 1–28.
    - A. Calderon and N. Salter, "Higher spin mapping class groups and strata of Abelian differentials over Teichmüller space," (2019) submitted. arXiv:1906.03515.
    - A. Calderon, "Connected components of strata of Abelian differentials over Teichmüller space," Comment. Math. Helv. (2019) accepted. arXiv:1901.05482.

- A. Calderon, S. Coles, D. Davis, J. Lanier, and A. Oliveira, "How to hear the shape of a billiard table," (2018) submitted. arXiv:1806.09644.
- C. Adams, A. Kastner, A. Calderon, X. Jiang, G. Kehne, N. Mayer, and M. Smith, "Volume and determinant densities of hyperbolic rational links," J. Knot Theory *Ramifications* **26** (2017) 1750002.

10. Professional development activities:
    - Workshop participant:
      - Holomorphic differentials in mathematics and physics, MSRI, 2019
      - Combinatorial and algebraic aspects of geometric structures, Chiang Mai University, Thailand, 2019
      - Flat surfaces and dynamics on moduli space II, Casa Matemática Oaxaca, Mexico, 2019
      - Dynamics and moduli spaces of translation surfaces, Fields Institute, Toronto, 2018
      - Geometry and topology of 3-manifolds, Okinawa Institute of Science and Technology, 2018
      - Polygonal Billiards Research Cluster, Tufts University, 2017
      - Geometric Topology, Provo, UT, 2017
      - Topology Students Workshop, Georgia Institute of Technology, 2016
    - Short course participant:
      - Teichmüller dynamics, mapping class groups, and applications, Summer School and Conference, Institut Fourier, Grenoble, 2018
      - Introduction to geometry, dynamics, and moduli in low dimensions, LMS–CMI Research School, University of Warwick, 2017

1. Name and academic rank: Marketa Havlickova
Senior Lecturer of Mathematics

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Pure Mathematics, Massachusetts Institute of Technology, 2008
M.S.	Mathematics, University of California, Berkeley, 2003
B.S.	Pure Mathematics, Massachusetts Institute of Technology, 2002

3. Academic experience with institution rank and title:
- Senior Lecturer, Mathematics, Yale University, 2015–present
- Lecturer, Mathematics, Yale University, 2012–2015
- Gibbs Assistant Professor, Mathematics, Yale University, 2008–2012

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Richard H. Brodhead ’68 Prize for Teaching Excellence by a Non-ladder Faculty Member, Yale University, 2016
- Liftoff Fellowship, Clay Mathematics Institute, 2008
- Praecis Presidential Fellow, MIT, 2003
- University Fellow, UC Berkeley, 2003

8. Service activities (within and outside Yale): N/A

9. Most important publications and/or presentations (last five years): N/A

10. Professional development activities: N/A

1. Name and academic rank: Thomas Hille
Instructor of Mathematics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mathematics, Yale University, 2020
M.Phil. Mathematics, Yale University, 2016
M.Sc. Mathematics, ETH Zurich, Switzerland, 2014

3. Academic experience with institution rank and title:
- Instructor, Mathematics, Yale University, 2014–present

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Graduate Fellowship (Robert Willets Carle Fellow), Yale University

8. Service activities (within and outside Yale):
Within Yale:
- Co-organizer, Mathematics Directed Reading Program, Yale University, 2016
- Co-organizer, Mathematics Graduate Student Seminar Series, Yale University, 2015–2016

9. Most important publications and/or presentations (last five years):
- P. Buterus, F. Gotze, T. Hille, and G. Margulis, "Distribution of values of quadratic forms at integral points," (2019) submitted.
- P. Buterus, F. Gotze, and T. Hille, "On small values of indefinite diagonal quadratic forms at integer points in at least five variables," (2019) submitted.
- Invited presentations:
  - Number Theory Seminar, Rutgers, March 2020
  - Dynamics Seminar, Penn State, February 2020
  - Dynamics and Number Theory Seminar, Brandeis University, January 2020
  - Group Actions and Dynamics Seminar, Yale University, November 2019
  - Dynamics Seminar, Institute for Advanced Study (IAS), Princeton University, November 2019
  - Analysis Seminar, Yale University, October 2019
  - Graduate Student Seminar, Yale University, September 2016
  - Mathematical Sciences Research Institute (MSRI), UC Berkeley, "Geometric and Arithmetic Aspects of Homogeneous Dynamics," February 2015
  - Graduate Student Seminar, Yale University, February 2015

10. Professional development activities: N/A

1. Name and academic rank: Ethan Meyers
Visiting Associate Professor of Statistics and Data Science

2. Degrees with disciplines, institutions, and dates:
Ph.D. Computational Neuroscience, Massachusetts Institute of Technology, 2010
B.A. Computer Science, Oberlin College, 2002

3. Academic experience with institution rank and title:
- Visiting Associate Professor, Statistics & Data Science, Yale University, 2020–present
- Visiting Assistant Professor, Statistics & Data Science, Yale University, 2019
- Assistant Professor, Statistics, Hampshire College, 2014–present
- Research Affiliate, Center for Brains, Minds, and Machines, Massachusetts Institute of Technology, 2014–present
- Postdoctoral Associate, McGovern Institute for Brain Research, Massachusetts Institute of Technology, 2010–2014

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Society for Neuroscience (SfN), American Statistical Association (ASA)

7. Honors and awards:
- Statistical Partnerships among Academe, Industry, and Government (SPAIG), with nine other people, 2019
- Hubert Schoemaker Graduate Student Fellowship, 2009–2010
- National Defense Science & Engineering Graduate (NDSEG) Fellowship, 2006–2009
- Sigma Xi Scientific Research Society, 2005
- Phi Beta Kappa and High Honors in Computer Science, Oberlin College, 2002

8. Service activities (within and outside Yale):
Outside Yale:
- Member, Hampshire College Executive Committee of the Faculty, 2018–2019
- Chair, Hampshire College Education Policy Committee, 2015–2017
- Co-organizer, MIT CBMM Face Identification Workshop, 2015
- Member, Hampshire College Cognitive Science Faculty Search Committee, 2015
- Webmaster, Five College Statistics Program, 2015–present
- Member, MIT BCS Colloquium Committee, 2013–2014
- Co-Chair, MIT BCS Postdoc Committee, 2012–2014

9. Most important publications and/or presentations (last five years):
- E. Meyers, "Dynamic population coding and its relationship to working memory," J.

Neurophysiology **120** (2018) 2260–2268.

- E. Meyers, A. Liang, F. Katsuki, and C. Constantinidis, "Differential processing of isolated object and multi-item pop-out displays in LIP and PFC," Cerebral Cortex **28** (2017) 3816–3828.
- T. Poggio and E. Meyers, "Turing++ questions: A test for the science of (human) intelligence," AI Magazine **37** (2016) 73–77.
- E. Meyers, M. Borzello, W. Freiwald, and D. Tsao, "Intelligent information loss: The coding of facial identity, head pose, and non-face information in the macaque face patch system," J. Neuroscience **35** (2015) 7069–7081.
- L. Isik, E. Meyers, J. Leibo, and T. Poggio, "Timing of invariant object recognition in the human visual system," J. Neurophysiology **111** (2014) 61–102.

10. Professional development activities:
    - Developed courses on topics that are traditionally only taught at the graduate level, such as "Statistical Analysis of Neural Data" and "Statistical Learning."
    - Reviewer for several scientific journals (Nature Communications, Scientific Reports, J. Neuroscience, J. Neurophysiology, J. Cognitive Neuroscience, J. Neuroscience Methods, Cerebral Cortex, Frontiers in Psychology, Vision and Image Understanding)
    - Reviewer for the Neural Information Processing Systems Conference (NIPS)
    - Reviewer for MIT press and CRC press

1. Name and academic rank: Adriane Steinacker
Senior Lecturer of Physics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Astronomy, University of Bonn, Germany, 1995
Diploma Physics, University of Bonn, Germany, 1991

3. Academic experience with institution rank and title:
- Senior Lecturer, Physics, Yale University, 2019–present
- Lecturer, Physics, Yale University, 2016–2019
- Lecturer, Physics and Astronomy, University of California, Santa Cruz, 2010–2016
- Associate Adjunct Professor, Astronomy and Astrophysics, University of California, Santa Cruz, 2006–2010
- Lecturer, Astronomy, University of California, Santa Cruz, 2003–2006
- Postdoctoral Researcher, NASA Ames Research Center, Mountain View, CA, 2000–2005
- Research Assistant, Astronomy, Ruhr-University, Germany, 1999–2000
- Postdoctoral Researcher, Institute for Astrophysics, University of Jena, Germany, 1999
- Postdoctoral Fellow, German Research Foundation (DFG), Institute for Astrophysics, University of Jena, Germany, 1997–1998
- Postdoctoral Fellow, Max Planck Society (MPG), Jena, 1996

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- Poorvu Family Fund for Academic Innovation Award, 2019
- UC Santa Cruz Excellence in Teaching Ron Ruby Award, 2015
- UC Santa Cruz Diversity Award, 2009
- UC Santa Cruz Award for Excellence in Teaching, 2007
- National Research Council Postdoctoral Fellowship, 2000–2002
- Fellowship of the DFG (Deutsche Forschungsgemeinschaft), 1997–1998

8. Service activities (within and outside Yale):
Within Yale:
- Member, Teaching for the 21st Century Committee, Yale University, 2016–2017
- Consultant, ONEXYS Physics, Yale University, 2017–2018
- College Advisor, Pauli Murray College, Yale University, 2017–present

Outside Yale:
- Undergraduate Curriculum Committee, UC Santa Cruz: Chair, 2007–2011, Member, 2005–2006, 2015–2016

- Member, Academic Enrichment Committee, UC Santa Cruz, 2012–2013
- Undergraduate academic adviser in astrophysics, UC Santa Cruz, 2007–2011

9. Most important publications and/or presentations (last five years): N/A

10. Professional development activities:
- Speaker at various workshops and student events:
  - Guest speaker, Yale Summer Program in Astrophysics, 2017
  - Keynote speaker, MMATH (Math Majors of America Tournament for High Schools), 2017
  - Speaker, Graniterock Algebra Academy, "The scale of our solar system," 2015
  - Invited workshop speaker, Women in Physics Conference at UC Santa Cruz, "The role of illustrations in scientific communication," 2015
  - Speaker, UC Santa Cruz, "Venus transits through history," 2012
  - Speaker, Music of the Spheres, Lick Observatory, "What's life got to do with it? The new science of astrobiology," 2008
  - Speaker, Villa Montalvo, Saratoga, "Jupiter and its many friends and relations," 2008
- Scientific reviewer:
  - MIT Press and CRC Press, 2016–present
  - Astronomy and physics textbooks for Pearson (Addison-Wesley) , 2008–present
  - Astronomy and physics textbooks for McGraw-Hill, 2008–present
- Organizer, "Transit of Venus" observational event, UC Santa Cruz, 2012

1. Name and academic rank: Steven M. Tommasini
Research Scientist, Yale School of Medicine

2. Degrees with disciplines, institutions, and dates:
   Ph.D. Biomedical Engineering, City University of New York Graduate Center, 2008
   M.S. Biomedical Engineering, City College of New York, 2002
   B.S. Biomedical Engineering, Columbia University, 2000

3. Academic experience with institution rank and title:
   - Research Scientist, Yale School of Medicine, 2018–present
   - Assistant Professor, Yale School of Medicine, 2011–2018
   - Post-Doctoral Associate, Stony Brook University, 2008–2011
   - Research Coordinator, Mount Sinai School of Medicine, 2001–2008

4. Non-academic experience:
   - Rehabilitation Engineering Research Center, NYU School of Medicine: Assisted in acquisition of data collection for the VA NYHHCS Lower Limb Prosthetics–Orthotics Optical Digitizer research and development project, 1999
   - IT Support, The Depository Trust and Clearing Corporation, 1995–2000
   - WKCR 89.9 FM-NY: Publicity Director, 1999-2000. Engineer/Broadcaster – Sports Department, 1996–2001

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: American Society for Bone and Mineral Research (ASBMR), Orthopaedic Research Society (ORS)

7. Honors and awards:
   - ASBMR Young Investigator Travel Grant, 2010
   - ASBMR Plenary Poster Presentation, 2010 and 2006
   - ASBMR Harold M. Frost Young Investigator Award, 2010
   - Harold Shames Award for Graduate Academic Excellence, CUNY, 2008
   - ASBMR Young Investigator Travel Award, 2007
   - Doctoral Student Research Grant, CUNY, 2007
   - Sue Rosenberg Zalk Student Travel & Research Fund Award, CUNY, 2007, 2006, 2004
   - NIAMS-ASBMR Bone Quality Meeting Young Investigator Travel Award, 2005

8. Service activities (within and outside Yale):
   Within Yale:
   - Doctoral thesis committee for Ayo Loye, 2016–present
   - Doctoral thesis committee for Matthew Bersi, 2013–2016. Degree awarded 2016.
   - Women's Health Research at Yale Grant Reviewer, 2015–present
   - STARS I Summer Research Program Mentor, 2014

Outside Yale:

- DoD, PRMRP MSD Grant Reviewer, 2019–present
- Amity Public Schools Experiential Learning Program, Faculty adviser, 2019–present
- Orthopedic Research and Education Foundation, Resident Research Grant Reviewer, 2018–present
- Orthopaedic Research Society Annual Meeting, Abstract reviewer, 2014–present
- 60th Annual Meeting of the Orthopaedic Research Society, Poster tour leader, 2014
- Medical Research Council Fellowship Reviewer, 2013
- ASBMR Annual Meeting Abstract Reviewer, 2012–present.
- Reviewer for Journal of Bone and Mineral Research, Bone, Journal of Biomechanics, Calcified Tissue International, Reproduction, Fertility and Development, Materials, Journal of Visualized Experiments, International Journal of Molecular Sciences, Techniques in Orthopaedics, Osteoporosis International, PLOS One, Journal of Dental Research, Journal of Biomedical Engineering, eCells and Materials Journal, Peer J, 2005–present

9. Most important publications and/or presentations (last five years):

- H.E. King, S.M. Tommasini, A.B. Rodriguez-Navarro, B.Q. Mercado, and H.C.W. Skinner, "Correlative vibrational spectroscopy and 2D X-ray diffraction to probe the mineralization of bone in phosphate-deficient mice," J. Appl. Crystallogr. **52** (2019) 960–971.
- E. Amenta, H.E. King, H. Petermann, V. Uskoković, S.M. Tommasini, and C.M. Macica, "Vibrational spectroscopic analysis of hydroxyapatite in HYP mice and individuals with X-linked hypophosphatemia," Ther. Adv. Chronic Dis. **9** (2018) 268–281.
- M.C. Horowitz and S.M. Tommasini, "Fat and bone: PGC-1α regulates mesenchymal cell fate during aging and osteoporosis," Cell Stem Cell. **23** (2018) 151–153.
- G.M. Calabrese, L.D. Mesner, J.P. Stains, S.M. Tommasini, M.C. Horowitz, C.J. Rosen, and C.R. Farber, "Integrating GWAS and co-expression network data identifies bone mineral density genes SPTBN1 and MARK3 and an osteoblast functional module," Cell Syst. **4** (2017) 46–59.
- C.M. Macica, H.E. King, M. Wang, C.L. McEachon, C.W. Skinner, and S.M. Tommasini, "Novel anatomic adaptation of cortical bone to meet increased mineral demands of reproduction," Bone **85** (2016) 59–69.

10. Professional development activities:

- USBJI Young Investigator Initiative Grant Writing Workshop, 2012–present

1. Name and academic rank: Thomas VandenBoom
J. Willard Gibbs Assistant Professor of Mathematics

2. Degrees with disciplines, institutions, and dates:
Ph.D. Mathematics, Rice University, 2018
B.S. Mathematics and Statistics, University of Minnesota, 2013

3. Academic experience with institution rank and title:
- Gibbs Assistant Professor, Mathematics, Yale University, 2018–present

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards: N/A

8. Service activities (within and outside Yale):
Outside Yale:
- Graduate Mentor, Geometry Lab, Rice University, 2017
- Graduate Student Coordinator, Rice University, 2015–2017
- Lecturer, Math Circle, Rice University, 2014
- Master of Ceremonies, Mathematical Lecture Contest, Rice University, 2014

9. Most important publications and/or presentations (last five years):
- V. Bucaj, D. Damanik, J. Fillman, V. Gerbuz, T. VandenBoom, F. Wang, and Z. Zhang, "Positive Lyapunov exponents and a Large Deviation Theorem for continuum Anderson models, briefly," J. Func. Anal. **277** (2019) 3179–3186.
- V. Bucaj, D. Damanik, J. Fillman, V. Gerbuz, T. VandenBoom, F. Wang, and Z. Zhang, "Localization for the one-dimensional Anderson model via positivity and large deviation estimates for the Lyapunov exponent," Trans. Amer. Math. Soc. **372** (2019) 3619–3667.
- B. Eichinger, T. VandenBoom, and P. Yuditskii, "KdV hierarchy via Abelian coverings and operator identities," Trans. Amer. Math. Soc. Ser. B **6** (2019) 1–44.
- J. Fillman, D. Ong, and T. VandenBoom, "Spectral approximation for ergodic CMV operators with an application to quantum walks," J. Math. Anal. Appl. **467** (2018) 132–147.
- T. VandenBoom, "Reflectionless discrete Schrödinger operators are spectrally atypical," Comm. Math. Phys. **359** (2018) 499–514.
- I. Binder, D. Damanik, M. Lukic, and T. VandenBoom, "Almost-periodicity in time of solutions of the Toda lattice," C. R. Math. Rep. Acad. Sci. Canada **40** (2018) 1–28.

10. Professional development activities: N/A

Appendix C – Equipment

The Mechanical Engineering Program has significant equipment and instrumentation to support engineering teaching and design. This equipment and instrumentation are housed in the Greenberg Engineering Teaching Concourse, Materials Laboratory and Mechanical Testing Facility, Fluid Mechanics and Thermodynamics Laboratory, Mechanical Design Laboratory (including the Student Shop), and Center for Engineering Innovation and Design.

The **Greenberg Engineering Teaching Concourse** includes a variety of electrical, electronic, and fabrication equipment. Two MarkForged MARK TWO GEN 2 Desktop 3D printers (illustrated in Figure C-1) are available for student projects. The capabilities of the printers include printing with Onyx and continuous reinforcement with carbon fiber, Kevlar, and fiberglass, enabling significantly improved capabilities for functional prototyping. An additional three Makerbot Replicator+ Desktop 3D Printers (one is shown in Figure C-2) are available to serve student's needs. The capabilities of the printers include printing with Makerbot PLA material.

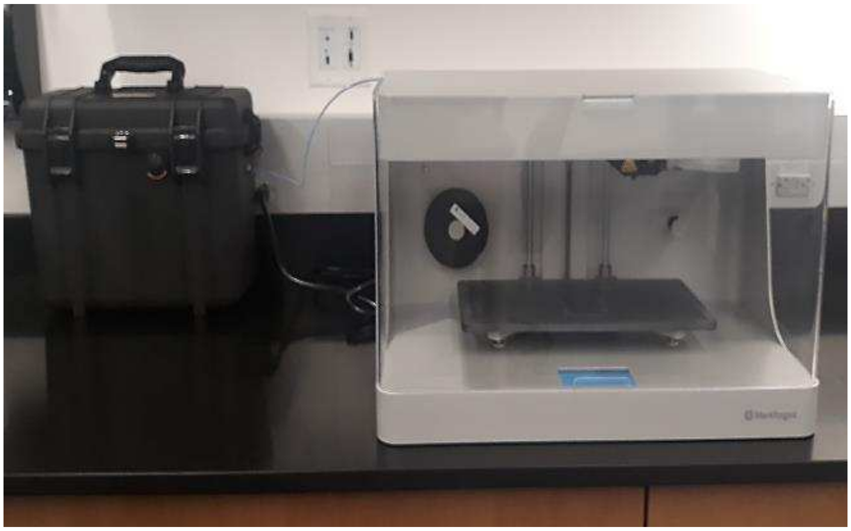


Figure C-1. MarkForged MARK TWO GEN 2 Desktop 3D printer located in the Greenberg Engineering Teaching Concourse.

Figure C-2. Makerbot Replicator+ desktop 3D printer located in the Greenberg Engineering Teaching Concourse.

The Greenberg Engineering Teaching Concourse is also used to support courses that include instruction in electronics, with 24 workstations in two labs geared toward this level of instruction (illustrated in Figures C-3 and C-4).

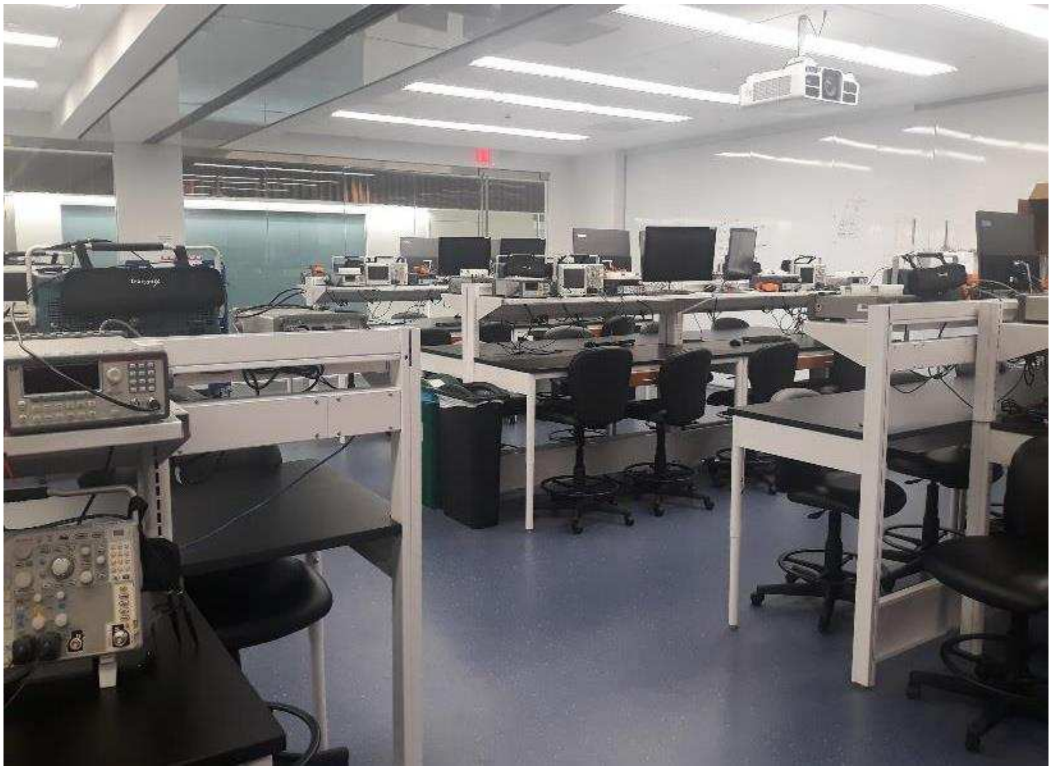


Figure C-3. Basic electronics instruction areas in the Greenberg Engineering Teaching Concourse.

Figure C-4. Basic electronics workstations in the Greenberg Engineering Teaching Concourse.

Each basic electronics workstation includes:

- Tektronix MDO3012 (2 channel) and MDO3014 (4 Channel) Mixed Domain 6-in-1 Oscilloscopes, which feature:
  - Oscilloscope
  - Spectrum Analyzer (3 GHz)
  - Arbitrary Function Generator
  - Logic Analyzer
  - Protocol Analyzer
  - Digital Voltmeter/Counter
  - Tek Visa USB Waveform Computer Capture
- Keithley 3390 50 MHz Arbitrary Waveform Generator
- ThinkCentre Lenovo Computer
- Keithley 2231A-30-3 Triple Channel DC Power Supply
- Keysight U1233A True RMS Multimeter

There are 60 computer workstations throughout the Teaching Concourse. Each computer workstation is equipped with the following design/simulation software:

- OceanView
- Adobe Acrobat XI Pro
- Arduino

- Aspen (Basic Engineering, Batch Process Developer, Aspen Energy Analyzer, Exchanger Design and Rating, Flare System Analyzer, OTS Framework)
- Atmel Studio 7.0
- MATLAB R2019a
- Microsoft suite
- National Instruments Software
- Tektronix OpenChoice
- SolidWorks (Electrical, Composer)

The **Materials Laboratory and Mechanical Testing Facility** houses materials testing instrumentation (tensile and hardness testers, micro and nano-indenters) and a differential scanning calorimeter, many of which were purchased within the last four years using funds from the Provost's Office. Becton Engineering Center Room 218 houses two pieces of Instron mechanical testing equipment with different load frames (shown in Figures C-5 and C-6), a Vickers hardness tester (shown in Figure C-7), a cold-rolling mill, a differential scanning calorimeter (shown in Figure C-8), an optical microscope (shown in Figure C-9), a stereo microscope (shown in Figure C-10), and a small furnace. Room 220 houses a nano-indenter scanning electron microscope and will also house a helium pyncnometer as soon as it is installed. (The March 2020 installation was postponed due to the pandemic.) Room 220A houses mechanical polishers for metallography (shown in Figure C-11) and an arc melter (shown in Figure C-12). More specific information about some of these pieces of equipment is given below.

- Leica M205C optical microscope: While the Materials Laboratory has some simple microscopes that have been used in the past, this $50K microscope was installed in Fall 2018 and brings new capabilities, such as automated 3D image formation, the ability to export to various software programs, automated data analysis for 2D images (e.g., grain size distributions), and autofocus, which are ideal for image analysis. In Fall 2020, a stage will be installed to further enhance the microscope's functionality.

- Vacuum high-temperature annealing furnace: Students investigate annealing of test samples in two laboratory exercises in the Solid Mechanics and Materials Science Laboratory course (MENG 286L): "Rolling, annealing, and hardness testing" and "Differential scanning analysis and X-ray diffraction." The annealing furnace is used to anneal cold-rolled brass samples to reverse the effect of rolling on the hardness. This vacuum furnace allows students to perform hands-on experimental studies of metals.

- Nano-indenter: Nano-indentation is perhaps the most versatile and widely used nanometer-scale mechanical characterization tool. In contrast to atomic force microscopy, which provides nanoscale structural characterization, nano-indentation probes the mechanical properties of nm-sized samples and devices. The nano-indenter is used by students pursuing materials-related investigations in Special Projects I and II (MENG 471, MENG 472, MENG 473, and MENG 474) to characterize the new materials they develop.

- Polishing system: In addition to several major equipment purchases, the metallurgy portion of MENG 286L was improved by upgrading the current facilities by adding two new polishing systems in 2019, which were purchased with funds from the Provost's Office. The polishing instrumentation can prepare polished brass samples after cold working and annealing for accurate hardness characterization.

- Helium pycnometer: In MENG 286L, students make their own metallic alloys and then determine various structural and mechanical properties of the alloys. The gas pycnometer is a relatively inexpensive instrument that — when it is installed —will allow students to determine accurately the density of the alloy that they have made and compare it with theoretical predictions based on the alloy's composition.

- Arc melter: The arc melter is a key component of the ME Program's plan to expand the materials science curriculum and upgrade the MENG 286L laboratory course from one-half credit to one credit. The arc melter is capable of making advanced alloys.

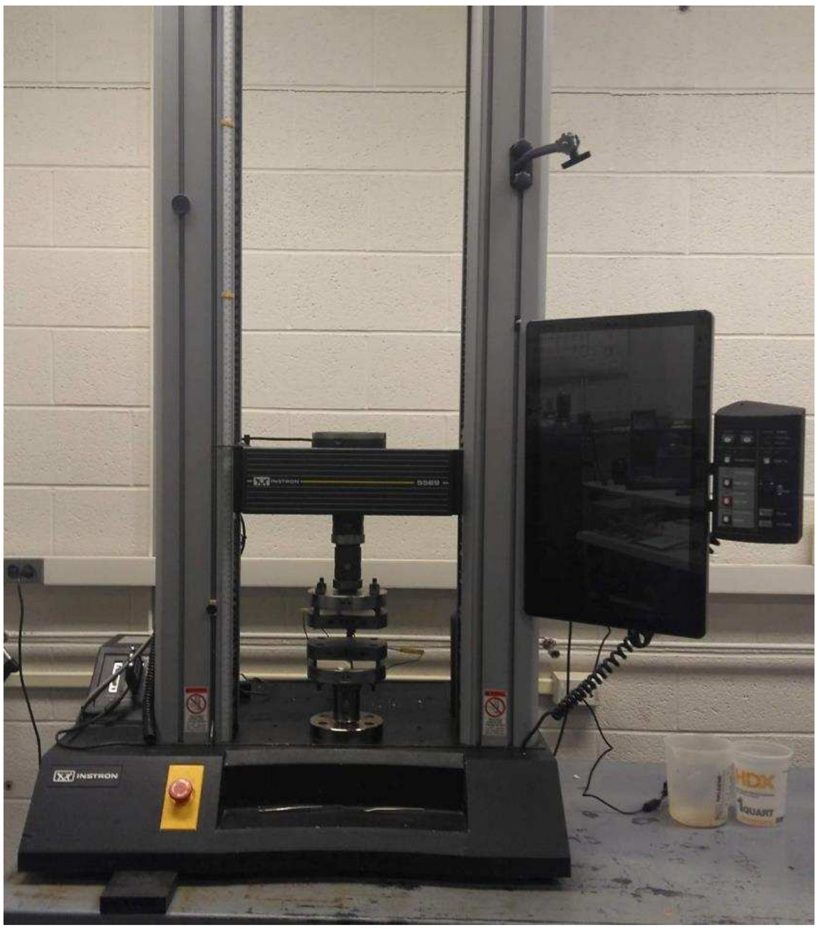


Figure C-5. Instron mechanical tester in the Materials Laboratory and Mechanical Testing Facility.

Figure C-6. Small Instron mechanical tester in the Materials Laboratory and Mechanical Testing Facility.

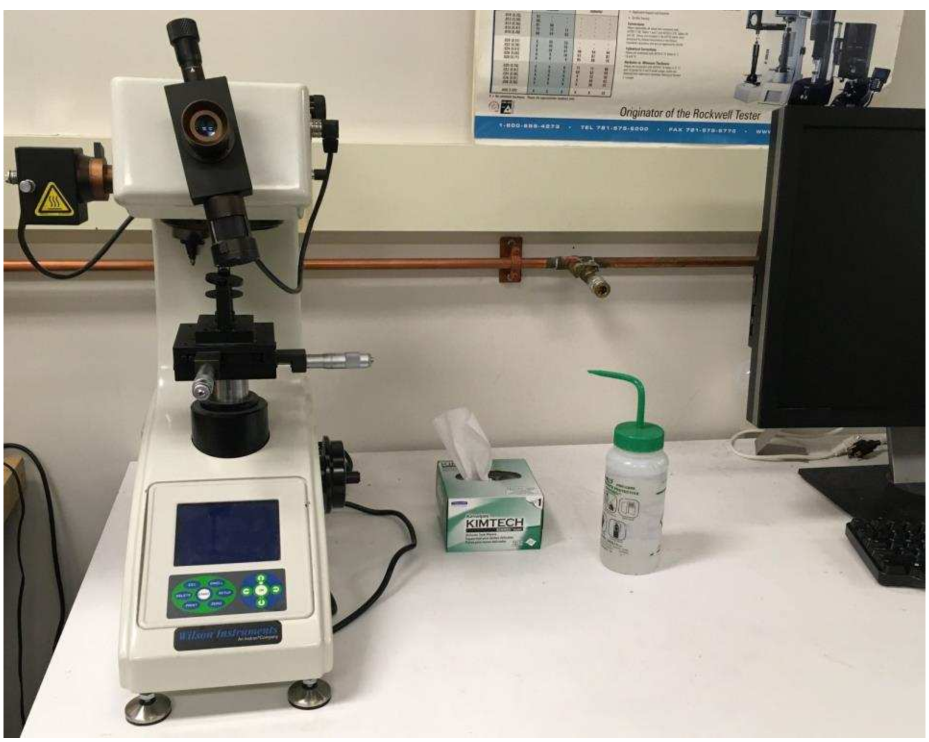


Figure C-7. Hardness tester in the Materials Laboratory and Mechanical Testing Facility.

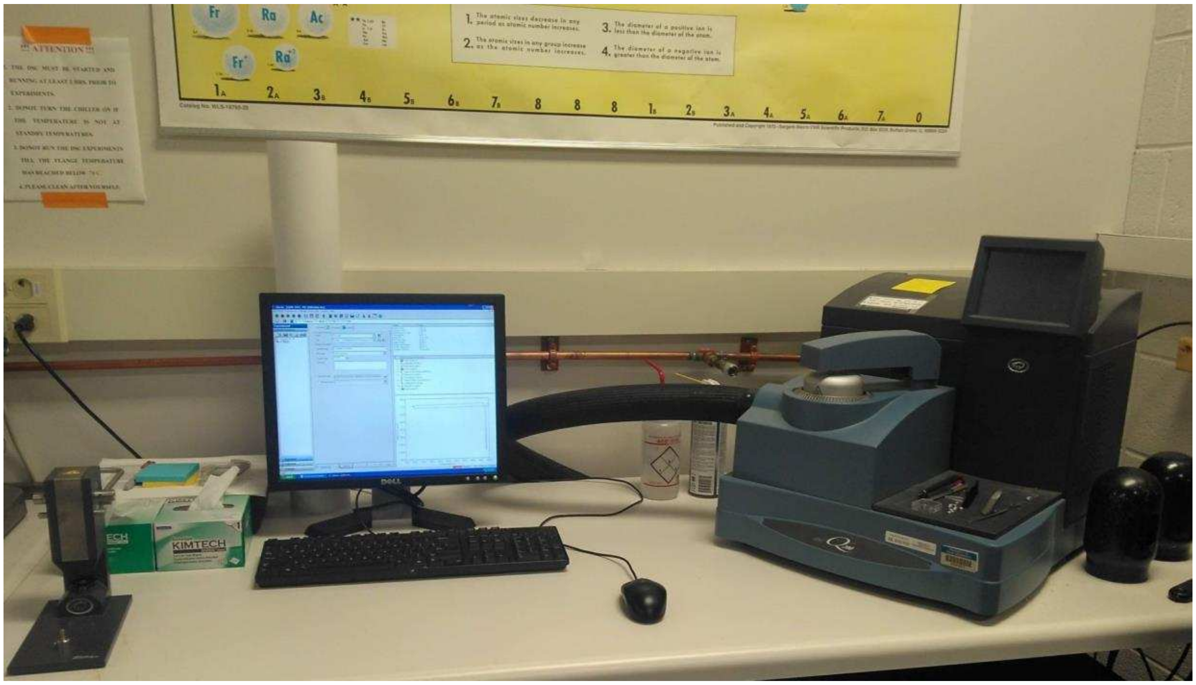


Figure C-8. Differential scanning calorimeter in the Materials Laboratory and Mechanical Testing Facility.

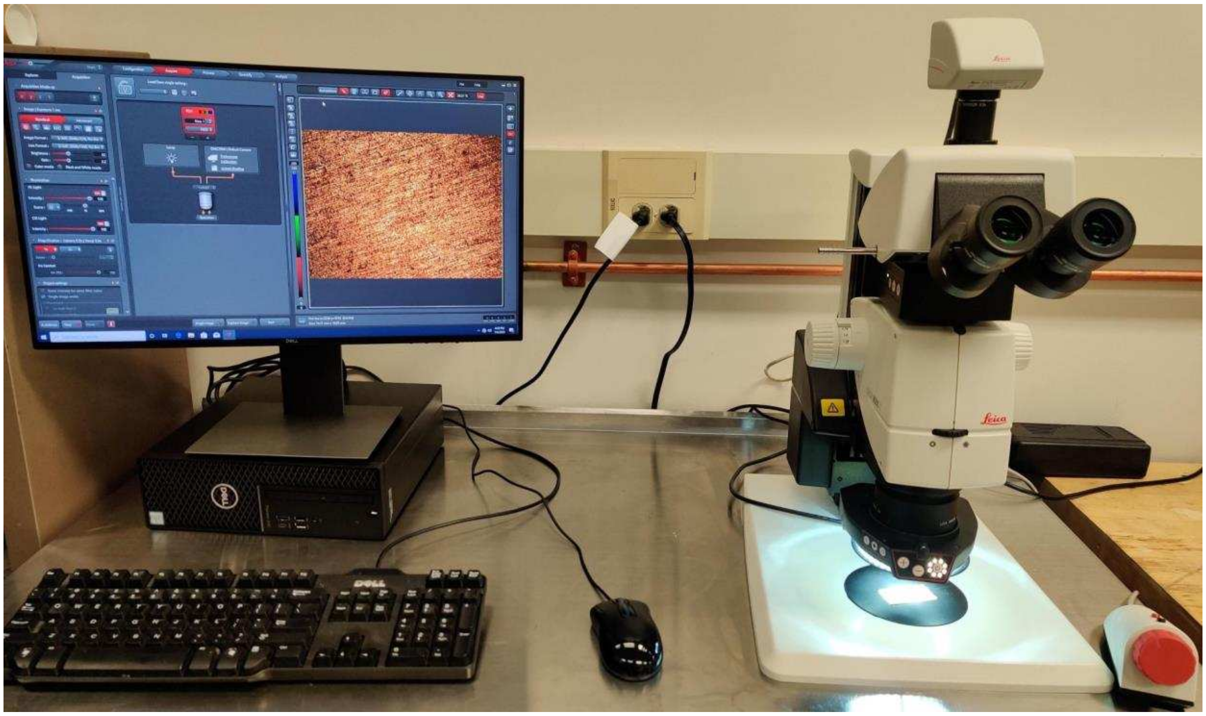


Figure C-9. Leica M205C optical microscope in the Materials Laboratory and Mechanical Testing Facility.

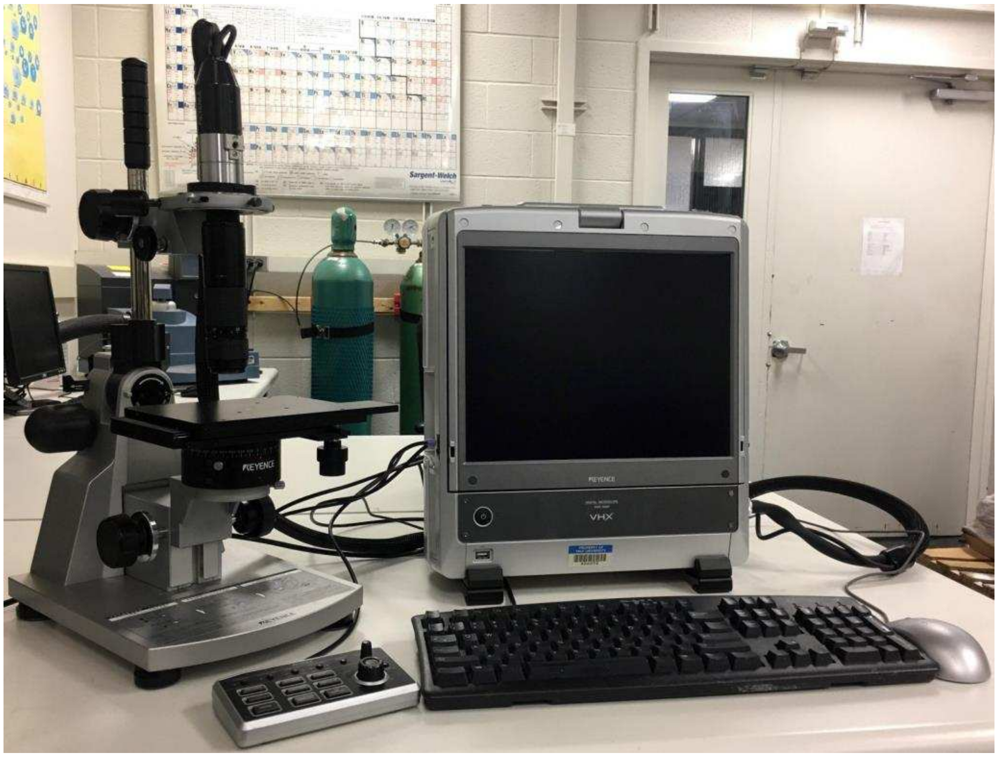


Figure C-10. Keyence stereo microscope in the Materials Laboratory and Mechanical Testing Facility.

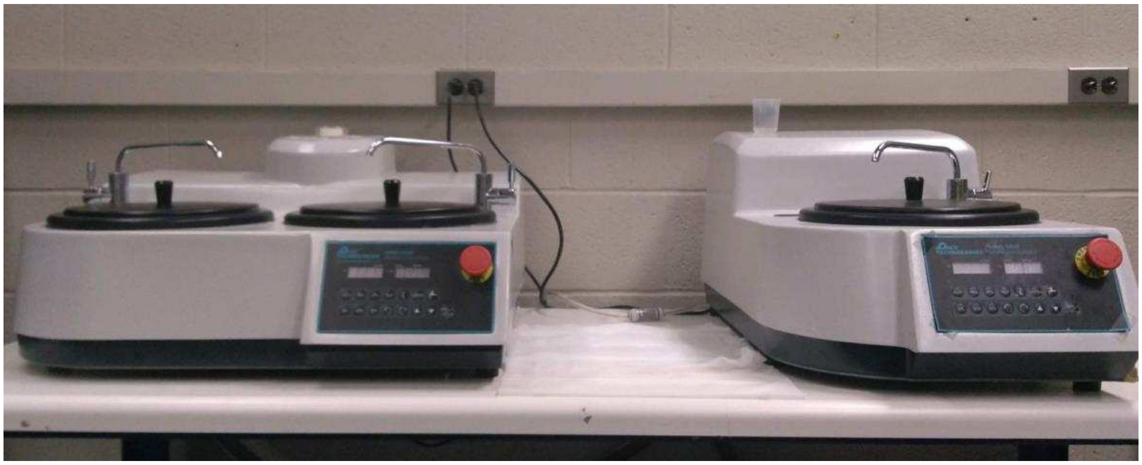


Figure C-11. Metallographic polishing equipment in the Materials Laboratory and Mechanical Testing Facility.

Figure C-12. Arc melter in the Materials Laboratory and Mechanical Testing Facility.

The **Fluid Mechanics and Thermodynamics Laboratory** includes rheometers (Anton-Paar MCR 302), viscometers, and tensiometers for measuring fluid properties, a rotating cylinder to study spin-up and spin-down of rotating fluids, and a subsonic wind tunnel that provides a platform for experiments ranging from boundary-layer characterizations to airfoil lift and drag measurements. Available instrumentation includes a variety of pressure probes and flow meters, a hot-film anemometry system from Dantec Dynamics, and dynamic balance for object lift and drag measurements. Dedicated translational stages to support the hot wire probe allow students to measure boundary layer profiles. The lab also includes a subsonic wind tunnel with a test section approximately 30 cm × 60 cm and 40 m/s velocity capability (illustrated in Figure C-13).

On the thermodynamics side, the instrumentation includes an oxygen bomb calorimeter (to characterize different fuels from food to conventional fuels), an internal combustion (IC) engine test stand, a fully instrumented turn-key gas turbine facility, an instrumented hydrogen fuel cell, and facilities for students to build and test simple dye-sensitized solar cells. The Modular Turbojet test cell (illustrated in Figure C-14) is an operating turbojet engine that is fully instrumented, allowing students to experience operations of a turbojet along with the ability to fully analyze the engine's Brayton cycle and calculate associated performance metrics. Students also study the operating characteristics of an instrumented IC engine/generator (illustrated in

Figure C-15). High-speed combustion pressure monitoring, crankshaft and ignition data collection, and fuel consumption and utility grade power (load) measurements allow the students to characterize the Otto combustion cycle and engine thermal efficiency at multiple load and fuel mixture conditions. A Heliocentris hydrogen fuel cell apparatus (illustrated in Figure C-16) is used by students to study and characterize fuel cell operating and performance limits.

This space also serves as an additional design/construction student workspace with hand tools and light machine tools including band saws and drill presses. Additionally, there is a Universal Laser System VLS-6.60 enclosed laser cutter/engraver (with a 60-watt laser and a 32” × 18” processing area) for project and prototype fabrication use.

Figure C-13. Subsonic wind tunnel in the Fluid Mechanics and Thermodynamics Laboratory.

Figure C-14. Modular Turbojet test cell in the Fluid Mechanics and Thermodynamics Laboratory.

Figure C-15. Instrumented internal combustion engine in the Fluid Mechanics and Thermodynamics Laboratory.

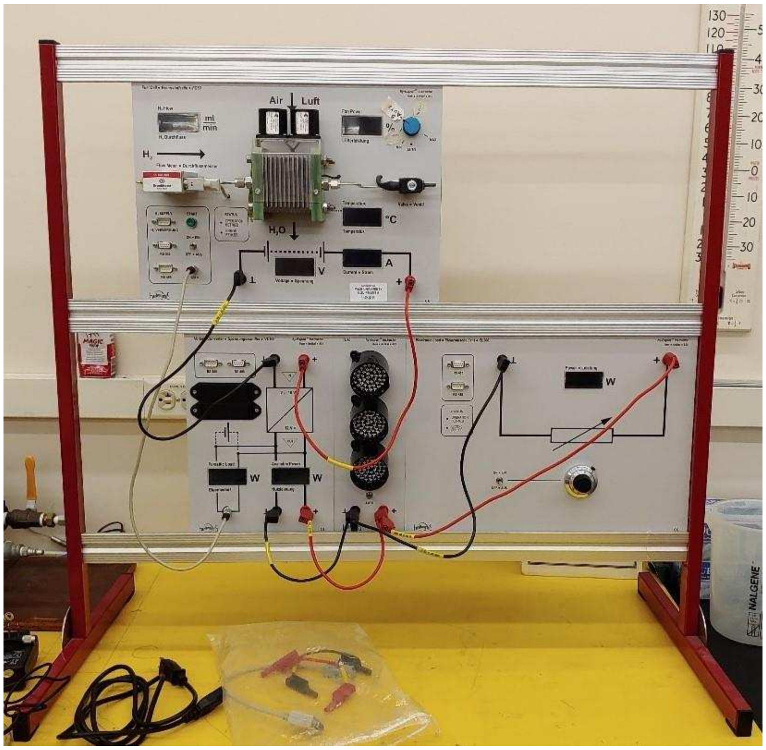


Figure C-16. Heliocentris hydrogen fuel cell apparatus in the Fluid Mechanics and Thermodynamics Laboratory.

The **Mechanical Design Laboratory**, which includes the **Student Shop**, is housed in Mason Laboratory Rooms B-7 and B-8. The equipment includes a Turn-Pro 7” metal band saw (drop arm type), two Wilton 14” Tradesman 1 HP 6-speed band saws, a Wilton 4200 belt/disc sander, a Dayton 1/3 HP belt drive drill press, a Wen 125-1072 5-speed drill press, an Atlas mandrel press, a Baileigh HP-160 sheet metal punch, a Baileigh SN-F16-HN manual corner notcher, metal breaks, a Grizzly All-Purpose Bender for metal, a Phase II 265-110 hand tapper, and a Universal VersaLaser laser cutter. Laser cutters allow excellent “rapid prototyping” capabilities (with easy tie-ins to CAD models), and they use a range of inexpensive materials. Demo boards for electric and pneumatic actuators help students compare the pros and cons of various actuators easily, and the “inspiration shelf” contains partially disassembled or cut-away assemblies to inspire design ideation. In addition, there is a wide selection of hand tools and a large stockpile of mechanical parts, including bearings, motors, casters, and gears. Some of the equipment in the Mechanical Design Laboratory and Student Shop is illustrated in Figures C-17 through C-25.

Figure C-17. Turn-Pro 7” metal band saw (drop arm type) in the Mechanical Design Laboratory and Student Shop.

Figure C-18. One of two Wilton 14” Tradesman 1 HP 6-speed bandsaws (left) and a Wilton 4200 belt/disc sander with vacuum (right) in the Mechanical Design Laboratory and Student Shop.

Figure C-19. A Dayton 1/3 HP belt drive drill press (left) and a Wen 125-1072 5-speed drill press (right) in the Mechanical Design Laboratory and Student Shop.

Figure C-20. Baileigh SN-F16-HN manual corner notcher in the Mechanical Design Laboratory and Student Shop.

Figure C-21. Grizzly All-Purpose Bender for metal (and lockout PPE for servicing machines) in the Mechanical Design Laboratory and Student Shop.

Figure C-22. Phase II 265-110 hand tapper, a tap set, cutting fluid, a machinist's vise, and measuring tools in the Mechanical Design Laboratory and Student Shop.

Figure C-23. Universal VersaLaser laser cutter and computer in the Mechanical Design Laboratory and Student Shop.

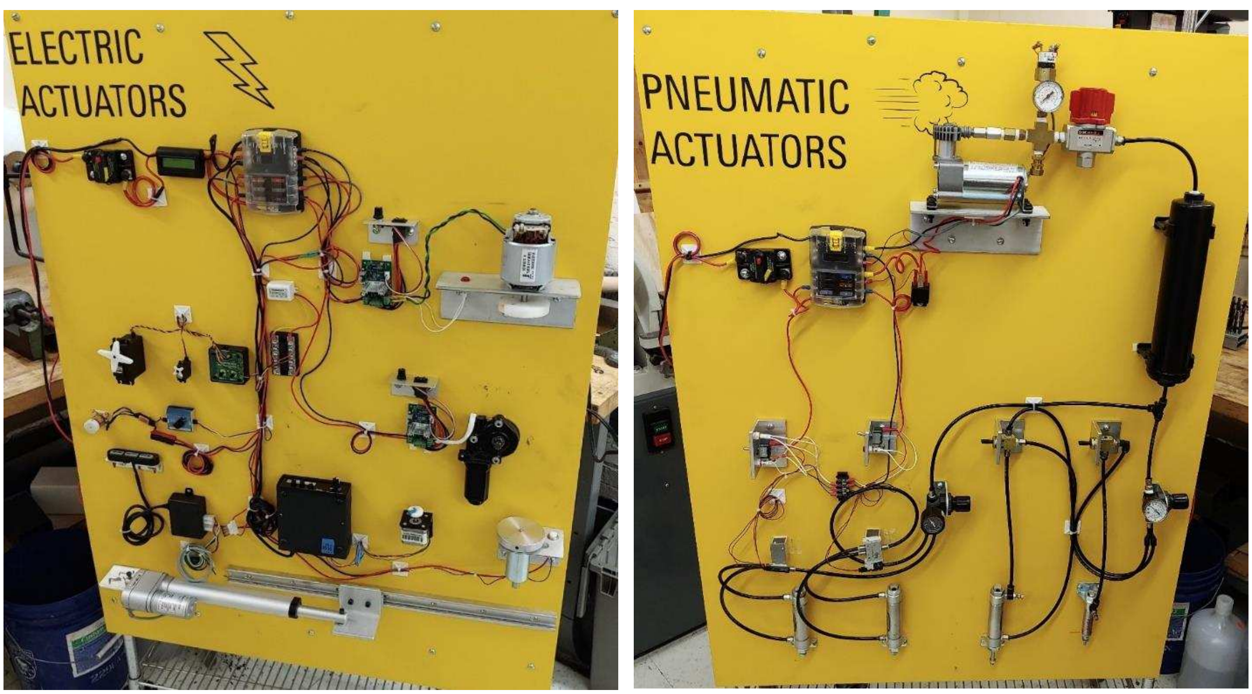


Figure C-24. Demo boards for electric and pneumatic actuators in the Mechanical Design Laboratory and Student Shop.

Figure C-25. Hand tools station in the Mechanical Design Laboratory and Student Shop. The top row contains safety glasses, Allen wrenches, center punches, tin snips, marking tools, box cutters, scissors, needle-nose pliers, wire strippers, and terminal crimpers. The middle row contains wrench sets, various types of screwdrivers, C-clamps, socket wrenches, and slip-joint pliers. The bottom row contains rivet tools, vise grips, metal hole punches, measuring tools, hammers, metal files, and metal saws. On the desk are calipers, a micrometer, and tool kits.

The equipment in the **SEAS Machine Shop** includes several lathes, milling machines, and drill presses and a variety of other equipment as listed in Table C-1, which continues onto the next page. The equipment is illustrated in Figures C-26 through C-34.

Table C-1. List of Equipment in the SEAS Machine Shop.

SEAS Machine Shop Equipment	Quantity	Description
Haas Toolroom TL 1	1	CNC lathe
Clausing 600-group 13-inch lathes	2	Lathe
Sharp 1118H	1	Precision lathe
Jet GH-1640ZX	1	Precision lathe
Acer E-mill 3VS	3	Milling machine
Sharp precision CNC milling machine	2	CNC milling machine
Jet 20-inch band saw	1	Band saw
Wilton 6-inch belt sander	1	Belt sander
Baldor 2-inch belt sander	1	Belt sander
Baldor pedestal grinder	1	Pedestal grinder
Lincoln power mig welder	1	Metal inert gas welder

ProtoMax by Omax	1	Waterjet cutter
Dayton drill press	1	Drill press
MSC drill press	1	Drill press
Powermatic drill press	1	Drill press
Trinco dry blast sand blaster	1	Sand blaster
DI-ACRO sheet metal brake	1	Sheet metal brake
DI-ACRO sheet metal sheer	1	Sheet metal shear
Rotex sheet metal hole punch	1	Sheet metal hole punch
DI-ACRO sheet metal pinch roller	1	Sheet metal pinch roller

Figure C-26. Haas Toolroom TL 1 CNC lathe in the SEAS Machine Shop.

Figure C-27. Clausing metal lathe in the SEAS Machine Shop.

Figure C-28. One of the Acer E-mill 3VS milling machines in the SEAS Machine Shop.

Figure C-29. Sharp precision CNC milling machine in the SEAS Machine Shop.

Figure C-30. Jet 20-inch band saw in the SEAS Machine Shop.

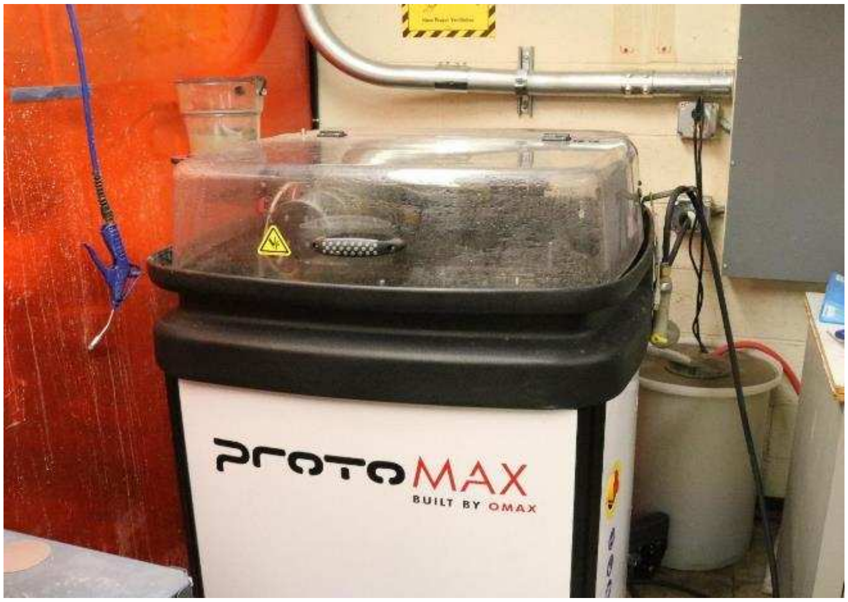


Figure C-31. ProtoMax waterjet in the SEAS Machine Shop.

Figure C-32. Drill presses in the SEAS Machine Shop.

Figure C-33. Sheet metal forming equipment in the SEAS Machine Shop.

Figure C-34. Sheet metal shear in the SEAS Machine Shop.

The **Center for Engineering Innovation and Design (CEID)** contains a variety of tools and equipment accessible to students in the **Studio** (including the **Electronics Stations**), **Machine and Metal Shop**, **Wood Shop**, and **Wet Lab**.

Studio: The CEID Studio equipment includes the array of 3D printers (Figure C-35 and Figure C-36) and hand tools listed in Table C-2. Note that the equipment in the CEID Electronics Stations is listed separately later.

Table C-2. List of Equipment in CEID Studio.

Equipment	**Quantity**	**Description**
Aticio MP C300	1	Printer
Camm-1 Servo	1	Vinyl cutter
Dell	5	Computer
Mac	2	Computer
Objet 30 Pro	1	3D printer
Stratasys F270	1	3D printer
Makerbot Replicator	1	3D printer
Makerbot Replicator 2	1	3D printer
Makerbot Replicator 2x	1	3D printer
Milwaukee 3.8” Right Angle Drill	1	Right angle drill
Milwaukee M18 Red Lithium	2	18 volt impact driver
M18 Red Lithium Drill	3	Drill
Milwaukee HackZall	1	Reciprocating saw
Milwaukee Jig Saw	1	Jig saw
Dremel 4000	2	Dremel tool
Janome Model HD-1000	1	Sewing machine
Canon EOS Rebel T3i	1	Camera

Figure C-35. One of the Makerbot 3D printers in the CEID Studio.

Figure C-36. Stratasys and Objet 3D printers in the CEID Studio.

Electronics Stations: The CEID Electronics Stations (Figure C-37) each have the equipment in the list below. Each station gives students the capability to assemble prototype circuits on breadboards and PC boards, and to evaluate, test, and debug the circuits using a variety of diagnostic equipment.

- Techtronix TBS 2000 Series Digital Oscilloscope
- Techtronix AFG1022 Function Generator
- Keithley 2231A-30-3 Triple Channel DC Power Supply
- Weller WES51 Soldering Iron
- Weller WSA350 Smoke Absorber
- Panavise Circuit Board Vise
- Aoyue Int 2702A Repairing System for soldering/de-soldering
- Fluke 179 True RMS Multimeter
- HP 973A Multimeter
- Prototyping Breadboards
- Arduino hardware
- Electronics components (resistors, capacitors, transistors, op amps, LEDs, servos, sensors, etc.)

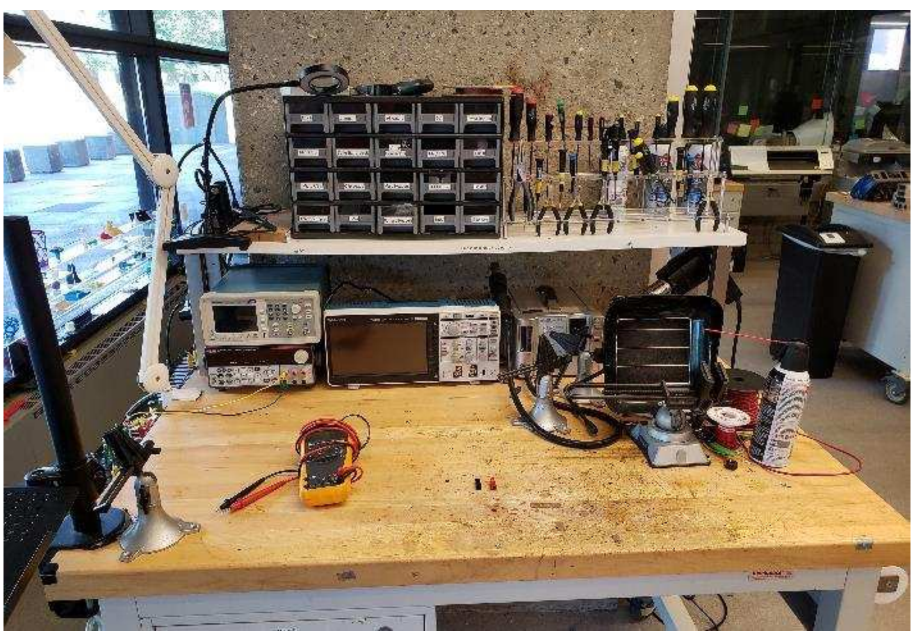


Figure C-37. Oscilloscope, soldering kit, multimeters, power supply, and function generator at one of the CEID Electronics Stations.

Machine and Metal Shop Equipment: The CEID Machine and Metal Shop includes the equipment listed in Table C-3 and pictured in Figures C-38 through C-45.

Table C-3. List of equipment in the CEID Machine and Metal Shop.

Machine and Metal Shop Equipment	**Quantity**	**Description**
ULS Laser Cutter 4’ × 2’	1	Laser cutter
Tormach PCNC 440	1	CNC mill
Jet VBS-2012	1	Vertical band saw
Jet Beltsander	1	Belt sander
Jet JDP-12	1	Drill press
Jet AP-3	1	3-ton arbor press
Dayton 2XUVS	1	Hand tipper
Jet J-A5816	1	Drill press
Jet JBG-8A	1	Bench grinder
Jet J-4206A	1	Belt sander
Clausing EUS 08	2	Milling machine
Clausing M300	2	Lathe
DI-ACRO Model No. 12SR	1	Slip roller
DI-ACRO Model No. 24 Finger Brake	1	Bender
Tin Knocker	1	Hand turret punch
DI-ACRO Model No. 24HS	1	Shear
DI-ACRO Model No. O2TN	1	Notching machine

Figure C-38. Large drill press and belt sander in the CEID Machine and Metal Shop.

Figure C-39. CNC milling machines in the CEID Machine and Metal Shop.

Figure C-40. Several lathes in the CEID Machine and Metal Shop.

Figure C-41. Laser cutter CNC milling machine in the CEID Machine and Metal Shop.

Figure C-42. Vertical and horizontal band saws, arbor press, and drill press in the CEID Machine and Metal Shop.

Figure C-43. Tormach PCNC 440 CNC mill in the CEID Machine and Metal Shop.

Figure C-44. Metal shears, bender, and roller in the CEID Machine and Metal Shop.

Figure C-45. Metal sheet puncher and notcher devices in the CEID Machine and Metal Shop.

Wood Shop Equipment: The CEID Wood Shop includes the equipment listed in Table C-4 and pictured in Figures C-46 through C-49.

Table C-4. List of equipment in the CEID Wood Shop.

Wood Shop Equipment	**Quantity**	**Description**
Shopbot PRS Alpha	1	4’ × 4’ CNC milling/routing
ShopBot Desktop	1	2’ × 1.5’ CNC milling/routing
Jet JBOS-5	1	Oscillating spindle sander
Formech DT508	1	Thermoformer
Labconco	1	Fume hood
Jet JMS-10SCMS	1	Sliding compound miter saw

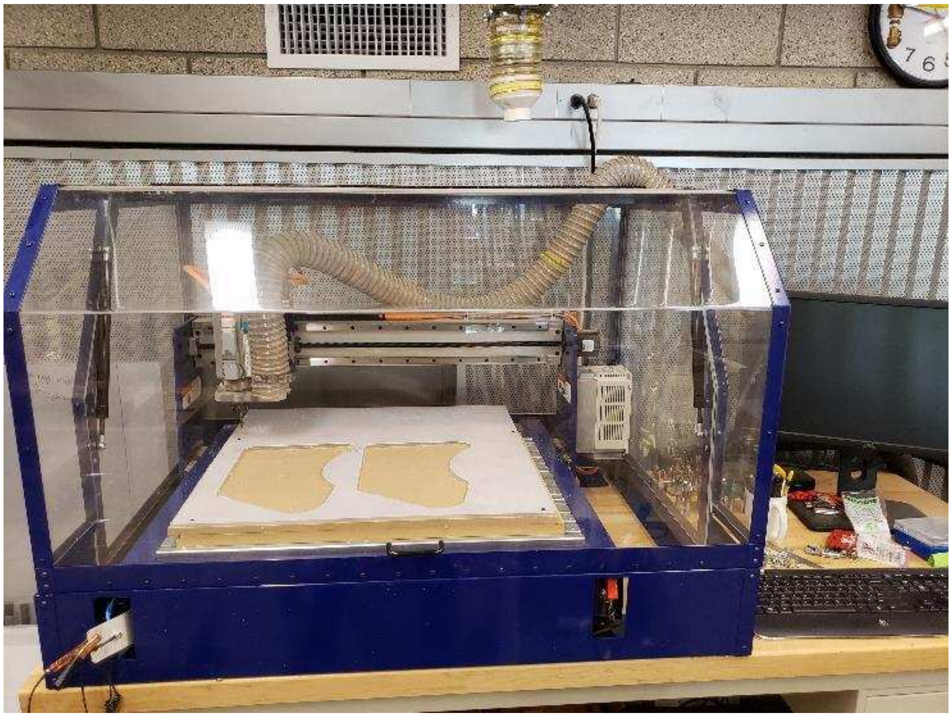


Figure C-46. ShopBot Desktop in the CEID Wood Shop.

Figure C-47. Shopbot PRS Alpha in the CEID Wood Shop.

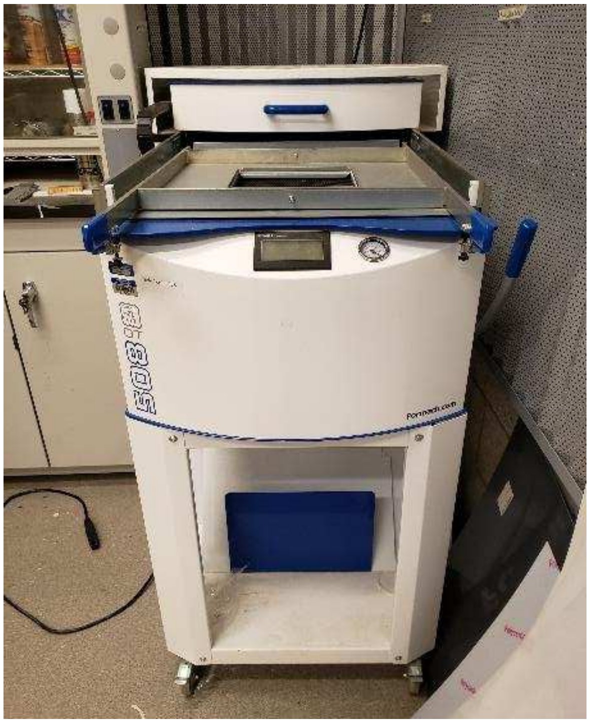


Figure C-48. Formech Thermoformer in the CEID Wood Shop.

Figure C-49. Fume hood/paint area in the CEID Wood Shop.

Wet Lab Equipment: The CEID Wet Lab has equipment shown in Figures C-50, C-51, and C-52 that is designed to serve several different engineering and design goals. One purpose is to facilitate genetic engineering techniques using E. coli. Polymerase reactions may be run and the results may be analyzed using spectroscopic techniques and electrophoresis. The following instruments are useful for this purpose:

- Fischer Scientific Isotemp Controlled Temperature Bath
- Fischer Scientific accuSpin Micro 17 Centrifuge
- Branson 2510 Ultrasonic Cleaner
- Oakton ION 2700 pH/mV/Ion/Temperature Meter
- Fischer Scientific Vortex Mixer
- Denver Instrument SI-114 Balance
- Whirlpool Microwave WMC20005YD-0
- MaestroGEN LB-16 UV Transilluminator
- Unico 2800 UV/VIS Spectrophotometer
- Fischer Scientific General Purpose Refrigerator/Freezer
- Fischer Scientific Isotemp Incubator
- BioRad T100 Thermal Cycler
- Fischer Scientific Model 664 Oven
- Fischer Scientific SterilElite 16 Autoclave
- BioRad GelDoc EZ Imager
- AMG Evos Fl Fluorescence Microscope
- New Brunswick Scientific Excell E24 Incubator Shaker Series
- Corning PC-420D Hot Plate
- Fischer Science Education Balance
- BioRad Sub-Cell GT Agarose Gel Electrophoresis Apparatus
- Fischer Scientific Mini Centrifuge
- Fischer Scientific Mini Roto S56 Mixer
- Gilson Pipetters
- Hamilton SafeAire II Fume Hood
- Bioforces nanosciences UV Ozone Procleaner

A second purpose is to support work in microfluidics, including both the standard variety using PDMS (polydimethylsiloxane) molds as well paper microfluidics more suited to diagnostics for the developing world. The following pieces of equipment support this type of research and engineering.

- Technical Innovations MHPM-UMV Schmidt Press
- Specialty Coating Services 6800 Spin Coater
- Vacuum Pump
- Vacuum Desiccator
- Xerox ColorQube 8570
- Nikon T1-SM Microscope
- Nikon SMZ 745T Microscope

- NCL 150 Fiber Optic Illuminators
- Hamilton SafeAire II Fume Hood

A third purpose is to house instruments that are used to remove support material from parts produced by the Stratasys and Objet 3D printers in the CEID Studio.

Figure C-50. Water baths and water jet cleaner in the CEID Wet Lab.

Figure C-51. Incubators, refrigerators, ovens, autoclave, shaker, and spectrometers in the CEID Wet Lab.

Figure C-52. Microscopes and electrophoresis gel reader in the CEID Wet Lab.

Other ancillary equipment for the Mechanical Engineering laboratory and design classes includes digital cameras, tachometer, 4-channel RC controller, universal frequency counter, USB data acquisition and thermocouple boards, triple beam balance, DC power supplies, AC/DC auto-charger, accelerometers, digital hanging scale, electronic scales, electronic wind speed indicator, Stirling engine, temperature controller, air compressor, lasers, water table, smoke tunnel, thermometers, transformers and voltage converters, model traffic light, contact angle measuring device, several microscopes, metal nibbler, solar panels, and radiation detector.

Appendix D – Institutional Summary

1. The Institution

a. Name and address of the institution

Yale University
New Haven, CT

b. Name and title of the chief executive officer of the institution

Peter Salovey
President

c. Name and title of the person submitting the Self-Study Report

Jeffrey Brock
Dean, School of Engineering & Applied Science

d. Name the organizations by which the institution is now accredited, and the dates of the initial and most recent accreditation evaluations.

Yale School of Engineering and Applied Science is accredited by:
- Accreditation Board for Engineering and Technology ABET – Engineering Accreditation Commission

Initial Accreditation:
- 1936–1965
- 1982–present

Most Recent accreditation evaluation:
- 2014: General Review

2. Type of Control

The type of managerial control of Yale is private, non-profit organization.

3. Educational Unit

Yale's School of Engineering & Applied Science (SEAS) consists of the Departments of Applied Physics, Biomedical Engineering, Chemical & Environmental Engineering, Computer Science, Electrical Engineering, and Mechanical Engineering & Materials Science. Chemical Engineering, Electrical Engineering, and Mechanical Engineering are ABET-accredited.

The Yale SEAS Department Chairs report to the Dean of SEAS on administrative and educational matters. Since August 2019, Jeffrey Brock has served as the Dean of SEAS. He also serves as the Dean of Science. An organizational diagram for SEAS is presented in Figure D-1.

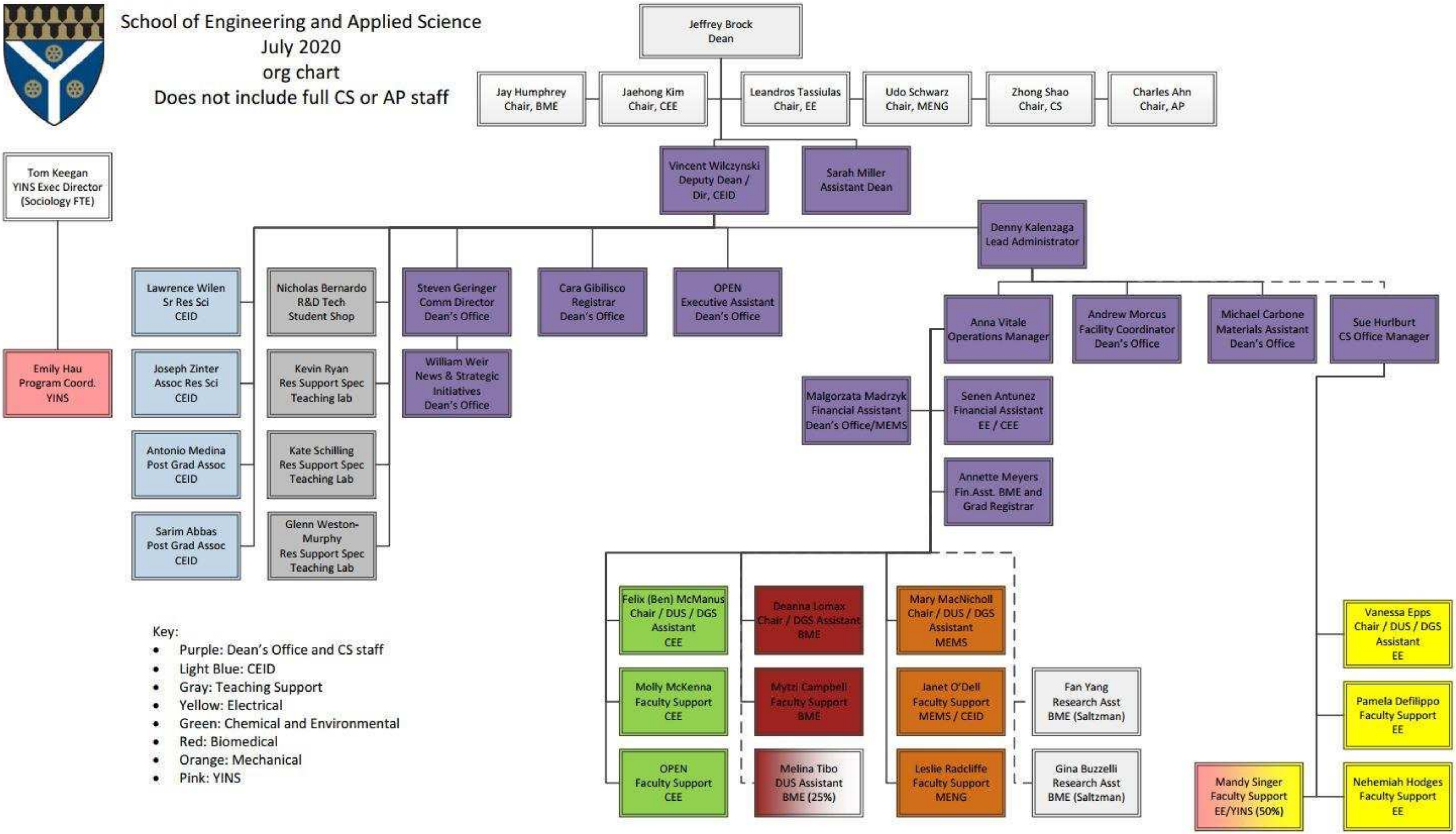


Figure D-1. Yale School of Engineering & Applied Science organizational diagram.

Yale is overseen by President Peter Salovey and the university's board of trustees, who comprise the governing and policy-making body known formally as the Yale Corporation. The institution is also led and supported by the University Cabinet, an advisory body convened by the president, which consists of the deans, vice presidents, and other senior academic and administrative leaders. Please note that Yale University no longer uses an organizational chart but rather details its structure using the following format (with direct links provided to Yale offices).

President & Trustees

- Peter Salovey, President
- Board of Trustees (The Yale Corporation)

University Cabinet

- Scott A. Strobel, Provost
- Deborah Berke, Dean, School of Architecture
- Robert Blocker, Henry & Lucy Moses Dean, School of Music
- John H. Bollier, Vice President for Facilities & Campus Development
- Jeffrey Brock, Dean, School of Engineering & Applied Science
- Nancy J. Brown, Jean and David W. Wallace Dean, School of Medicine
- James Bundy, Dean, School of Drama
- Ingrid C. "Indy" Burke, Carl W. Knobloch, Jr. Dean, School of Forestry & Environmental Studies
- Jack F. Callahan, Jr., Senior Vice President for Operations
- Kerwin K. Charles, Indra K. Nooyi Dean, School of Management
- Marvin Chun, Dean, Yale College
- Lynn Cooley, Dean, Graduate School of Arts & Sciences
- Alexander E. Dreier, Senior Vice President for Institutional Affairs, General Counsel, & Senior Counselor to the President
- Tamar Szabó Gendler, Dean, Faculty of Arts & Sciences
- Heather Gerken, Dean, Law School
- Susan Gibbons, Stephen F. Gates '68 University Librarian & Vice Provost for Collections and Scholarly Communication
- Kimberly M. Goff-Crews, Secretary & Vice President for University Life
- Ann Kurth, Dean, School of Nursing
- Marta Kuzma, Stavros Niarchos Foundation Dean, School of Art
- Pericles Lewis, Vice President for Global Strategy
- Janet E. Lindner, Vice President for Human Resources & Administration
- Stephen C. Murphy, Vice President for Finance & Chief Financial Officer
- Nathaniel Nickerson, Vice President for Communications
- Joan E. O'Neill, Vice President for Alumni Affairs & Development
- Gregory E. Sterling, The Reverend Henry L. Slack Dean, Divinity School
- David F. Swensen, Chief Investment Officer
- Sten H. Vermund, Dean, School of Public Health

Administrative Divisions - Each of Yale's vice presidents is responsible for oversight of one or more administrative offices of the university. The major subdivisions of each administrative unit are included in the listing below.

Secretary & Vice President for University Life

- Office of the Secretary and Vice President for University Life
- Chaplain's Office
- Office of LGBTQ Resources
- Student Accessibility Services

Senior Vice President for Institutional Affairs & General Counsel

- Office of General Counsel
- Office of Enterprise Risk Management
- Office of Federal and State Relations
- Office of Institutional Affairs

Senior Vice President for Operations

- Business Operations
- Office of Facilities
- Finance
- Human Resources and Administration
- Information Technology
- Office of New Haven and State Affairs
- Research Support
- Yale Hospitality

The senior vice president for operations is also responsible for the units reporting to the vice president for facilities and campus development, the vice president for finance & chief financial officer, and the vice president for human resources & administration.

- **Vice President for Alumni Affairs & Development**
  - Yale Alumni Association
  - Office of Development

- **Vice President for Communications**
  - Office of Public Affairs & Communications
  - Office of the University Printer
  - Yale Visitor Center

- **Vice President for Facilities & Campus Development**
  - Office of Facilities

- **Vice President for Finance & Chief Financial Officer**
  - Accounting & Financial Management
  - Budget Office (Financial Planning & Analysis)

- Business Solutions
- Controller's Office
- Financial Shared Services
- Procurement

- **Vice President for Global Strategy**
  - Gruber Foundation
  - Office of International Affairs
  - Office of International Students & Scholars
  - Poorvu Center for Teaching and Learning
  - Stephen A. Schwarzman Center
  - Yale-NUS New Haven Office

- **Vice President for Human Resources & Administration**
  - Human Resources & Administration
  - Emergency Management
  - Public Safety
  - Travel, Relocation & Fleet
  - Yale Printing & Publishing Services

4. *Academic Support Units*

Academic Support Unit	Responsible Name	Title
Department of Chemistry	Kurt Zilm	Chair
Department of Computer Science	Zhong Shou	Chair
English	Jessica Brantley	Chair
Mathematics	Yair Minsky	Chair
Applied Physics	Charles Ahn	Chair
Physics	Karsten Heeger	Chair
Department of Electrical Engineering	Leandros Tassiulas	Chair

5. *Non-Academic Support Units*

Non-Academic Support Unit	Responsible Name	Title
Yale College	Marvin Chun	Dean of Yale College
Engineering & Applied Science Library	Andrew Shimp	Librarian for Engineering & Applied Science, Chemistry, and Mathematics
Yale Information Technology Services	John Barden	Chief Information Officer
Yale Office of Career Strategy	Jeanine Dames	Director
Tsai Center for Innovative Thinking at Yale	Claire Leinweber	Executive Director

6. Credit Unit

One semester course normally represents 2.5 class hours (three 50-minute classes or two 75-minute classes) or 3.0 laboratory hours per week. One academic semester normally represents at least 13 weeks of classes, exclusive of final examinations. One academic year normally represents two academic semesters.

7. Tables

Enrollment and Personnel details are presented in Tables D-1 and D-2 on the next two pages.

Table D-1. Program Enrollment and Degree Data.

Mechanical Engineering

	Academic Year		Enrollment Year*					Total Undergrad	Total Grad	Degrees Awarded			
			1st	2nd	3rd	4th	5th			Associates	Bachelors**	Masters	Doctorates
Current Year	2019–2020	FT			39	39		78	47	N/A	17/39	0	6
		PT							0				
1 year prior to current year	2018–2019	FT			39	48		87	42	N/A	25/48	1	1
		PT							0				
2 years prior to current year	2017–2018	FT			48	37		85	41	N/A	15/37	0	8
		PT							0				
3 years prior to current year	2016–2017	FT			37	36		73	42	N/A	17/36	0	6
		PT							1				
4 years prior to current year	2015–2016	FT			36	38		74	38	N/A	20/38	0	4
		PT							1				

These are official fall term enrollment figures (head count) for the current and preceding four academic years and undergraduate and graduate degrees conferred during each of those years. The "current" year means the academic year preceding the on-site visit.

FT=full-time PT=part-time

* Yale College does not require students to declare a major until the end of their second year.
** Data reflect (BSME) / (total of BSME, BSES(ME), BAES(ME)).

Table D-2. Personnel.

Department of Mechanical Engineering & Materials Science

Year[1]: 2019–2020

	HEAD COUNT		FTE[2]
	FT	PT	
Administrative[2]	3*	-	3*
Faculty (tenure-track)[3]	14**	-	13.5**
Other Faculty (excluding student assistants)	4	5	2
Student Teaching Assistants[4]	36	-	18
Technicians/Specialists	2	-	2
Office/Clerical Employees	3	-	3
Others[5]	-	-	-

Report data for the program being evaluated.

1. Data on this table are for the fall term immediately preceding the visit. Updated tables for the fall term when the ABET team is visiting are to be prepared and presented to the team when they arrive.
2. Persons holding joint administrative/faculty positions or other combined assignments should be allocated to each category according to the fraction of the appointment assigned to that category.
3. For faculty members, 1 FTE equals what your institution defines as a full-time load.
4. For student teaching assistants, 1 FTE equals 20 hours per week of work (or service). For undergraduate and graduate students, 1 FTE equals 15 semester credit-hours (or 24 quarter credit-hours) per term of institutional course work, meaning all courses — science, humanities and social sciences, etc.
5. Specify any other category considered appropriate, or leave blank.

* Full-time faculty members serve as the Chair, Director of Undergraduate Studies, and Director of Graduate Studies, with teaching relief allocated to these positions.

** Full-time faculty allocations were applied for the Chair, Director of Undergraduate Studies, and Director of Graduate Studies, with teaching relief allocated to these positions.

Appendix E – Lectures and Seminars Hosted by the Center for Engineering Innovation and Design

The Yale Center for Engineering Innovation and Design (CEID) regularly hosts workshops, lectures, and social events. Table E-1 contains a list of these activities for the Academic Year 2019–2020. It is noted that the on-site activities were suspended in March when remote learning was put into place. In addition to these events, the CEID staff regularly host weekly programming that includes the following events: Orientations, Laser Cutter Trainings, Makerbot Trainings, Machine Shop/Wood Shop Trainings, Sewing Machine Trainings, Mechanical Engineering Office Hours, Product Development Office Hours, and Graphic Design Office Hours. Also, the CEID serves as a venue for Networking Events hosted by the Yale Office of Career Strategy, with these events scheduled on Monday nights to provide career guidance and opportunities to meet with engineering company recruiters.

Table E-1. CEID Workshops, Lectures, and Social Events.

Date	Event Name	Presenter(s)	Event Type
8/26/19	CEID Turns 7!	CEID Staff	Social
9/4/19	Study Break: Lego Build Night	CEID Staff	Social
9/11/19	Wednesday Workshop: SolidWorks	Yale Undergraduate Aerospace Association (YUAA)	Workshop
10/2/19	Wednesday Workshop: Chocolate	CEID Staff	Workshop
10/9/19	Wednesday Workshop: Woodworking	Lior Trestman, Shop Manager of MakeHaven	Workshop
10/23/19	Wednesday Workshop: Jack-O-Lantern	CEID Staff	Workshop
10/30/19	Wednesday Workshop: Costume-Making Study Break	CEID Staff	Workshop
11/5/19	CEID Lecture Series: Kevin Tan, Founder of Snackpass	Kevin Tan, Founder of Snackpass	Lecture
11/13/19	Wednesday Workshop: Bubbles!	Dr. Lawrence Wilen, CEID Staff	Workshop
11/20/19	Wednesday Workshop: Audio Amplifier	Yale Student Branch of IEEE	Workshop

12/4/19	Winter Study Break	CEID Staff	Social
12/9/19	Grace Hopper Birthday Party	CEID Staff	Social
12/9/19	Breakfast with Disney Imagineering President	Kareem Daniel, President of Disney Imagineering	Career
12/12/19	2020 Summer Fellowship Lunch and Info Session	CEID Staff	Info Session
1/14/20	2020 Summer Fellowship Lunch and Info Session	CEID Staff	Info Session
1/15/20	CEID Blue-Booking Break	CEID Staff	Social
1/17/19	Whiteboard Art Competition	CEID Staff	Social
1/22/20	Wednesday Workshop: Basic Hand Tools	Dr. Joseph Zinter, CEID Assistant Director	Workshop
1/24/20	Make or Break: Friday Fry-yay!	CEID Staff	Social
1/29/20	Wednesday Workshop: The Science Behind Modern Art	Dr. Katherine Schilling, SEAS, and Ms. Cindy Schwarz, Yale Art Conservator	Workshop
1/31/20	Make or Break: CEID Super Bowl Party!	CEID Staff	Social
2/5/20	Wednesday Workshop: Web Development	Antonio Medina, CEID Design Fellow	Workshop
2/7/20	Make or Break: Masquerade Mask Making	CEID Staff	Social
2/12/20	Wednesday Workshop: Chocolate	CEID Staff	Workshop
2/14/20	Make or Break: Hearts and Pop Tarts	CEID Staff	Social
2/19/20	Wednesday Workshop: Concrete	CEID Staff	Workshop
2/21/20	Make or Break: Becton Turns 50!	CEID Staff	Social
2/26/20	Wednesday Workshop: Portfolios	Dr. Vincent Wilczynski, CEID Director	Workshop

2/28/20	Make or Break: Leap Year, Cinnamon Rolls, and Time Capsules!	CEID Staff	Social
3/04/20	Wednesday Workshop: Flamin' Hot Photoshop!	Ashlyn Oakes, CEID Design Fellow	Workshop
3/06/20	Make or Spring Break	CEID Staff	Social
3/25/20	Wednesday Workshop: Web Design	Antonio Medina, CEID Design Fellow	Workshop
3/27/20	Make or Break: Origami!	CEID Staff	Social
4/01/20	Wednesday Workshop: Adobe CC Illustrator	Ashlyn Oakes, CEID Design Fellow	Workshop
4/02/20	Thursday Workshop: Fractal Art	Stefan Krastanov	Workshop
4/03/20	Make or Break: Watercolor Painting	CEID Staff	Social
4/08/20	Wednesday Workshop: TinkerCAD Circuits	Antonio Medina, CEID Design Fellow	Workshop
4/09/20	Thursday Workshop: Adobe CC Photoshop	Ashlyn Oakes, CEID Design Fellow	Workshop
4/10/20	Make or Break: Paper Airplanes	CEID Staff	Social
4/14/20	Seminar: Yale-China Art Fellowship Program Visiting Artist	Wong Chi-Yung, Visiting Artist	Seminar
4/14/20	Wednesday Workshop: Web Design with FlexBox	Sarim Abbas	Workshop
4/22/20	Wednesday Workshop: Rhino3D	Ashlyn Oakes, CEID Design Fellow	Workshop
4/23/20	Thursday Workshop: 3D Human Anatomy with Synopsys ScanIP	Dr. Steven Tommasini and Dr. Daniel Wiznia, Yale Medical School	Workshop
4/29/20	Wednesday Workshop: Analog Electronics with TinkerCAD	Antonio Medina, CEID Design Fellow	Workshop

Appendix F – Major Completion Form

Yale College Major Clearance Form
Please sign and return by April 9, 2020

University Registrar's Office
246 Church Street, 3rd Flr.
Fax: 432-2334

1) Check the major being awarded and write in any corrections. Circle the degree being awarded if prompted.

2) If the student has already met the requirements of the major, check the first box (this is a fairly rare situation).

3) If the student has not already met the requirements of the major, check the second box. Circle the courses the student needs to pass in order to fulfill the major requirements, and add any non-course requirements, such as a noncredit senior essay or comprehensive exam. Use the "comments" section to provide details about the requirements - for example, if a student only needs to pass two out of three circled courses, or if a course cannot be taken Credit/D/Fail.

4) For students fulfilling the requirements of two majors, check that the final program matches the approved plan of study and that the student does not have more than the permitted number of overlapping courses. The recommended practice is for the departments to exchange lists of the courses each is counting toward the major .

NAME: ID:

MAJOR: COLLEGE:

Other Major:

☐ This student has already completed the requirements as of the end of the last term and has nothing remaining at this time.

☐ This student has not yet completed the requirements of the major. The courses the student needs to pass and any non-course items needed to fulfill the major requirements are indicated below:

TrmYr	Subj Code	Crse Numb	Title	CR/D/F?

(continued)

Non-course requirements:

____

Comments:

DUS Signature | DUS Printed Name | Date

For questions contact Daria Vander Veer, Assistant University Registrar, 432-2338, daria.vanderveer@yale.edu

Appendix G – Extended Abstract for Mechanical Design: Process and Implementation I and II (MENG 487L/488L)

Mechanical Design: Process and Implementation I and II (MENG 487L/488L)
Yale School of Engineering &Applied Science
Fall 2019 and Spring 2020

NOTE: This extended abstract covers a single course that spans two semesters.

Course Objectives:
MENG 487L/488L is the capstone design course in the Mechanical Engineering Program. This course is a unique opportunity to apply and demonstrate your broad and detailed knowledge of engineering in a team effort to design, construct, and test a functioning engineering system. This course requires quality design, analyses/experiments to support the design effort, and the fabrication/testing of the engineered system, as well as proper documentation and presentation of results to a technical audience. In addition to this, you are expected to learn to start your design work early; iterate on your design often; treat all documents as "living documents" and update them frequently; record everything in your individual notebook; use models, experiments, prototypes, etc. to justify your ideas, providing adequate time to complete a task by "sandbagging" the expected time and starting early, and working collaboratively with a team.

Reference Texts: *Shigley's Mechanical Engineering Design*, Budynas and Nisbett, McGraw-Hill
FE Reference Handbook (http://ncees.org/exams/study-materials/download-fe-supplied-reference-handbook/)

Format: Lectures/Teamwork Sessions THUR (1:00-2:00) - Design Lab THUR (2:00-4:00)

Instructor: J. Booth (Lecturer, SEAS), assisted by the CEID/SEAS Teaching Support Staff & the Teaching Assistants

Fulfilling Mechanical Engineering Program Outcomes:
This capstone course in Mechanical Engineering is the culmination of your undergraduate engineering education. The course provides the opportunity to apply what you have learned through coursework and your life experiences to the activity that is the essence of engineering: DESIGN.

The accrediting agency for engineering programs, ABET, specifies the required educational outcomes for all undergraduate engineering majors. As established by ABET, engineering programs must demonstrate that their graduates have:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics – demonstrated through engineering analysis and individual notebooks

2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors – demonstrated through the engineering specifications, customer requirements, business case, and manufacturing considerations in the preliminary and critical design reviews.
3. An ability to communicate effectively with a range of audiences – demonstrated through the project binder and design reviews, especially the debriefing design review, and through soliciting customer feedback.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts – subject of a lecture on several ethics case studies, the subject of team meetings with instructors, and demonstrated in the customer requirements and customer feedback gathered by the student teams.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives – demonstrated by the peer evaluations, Gantt charts, and 3-9 reports.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions – demonstrated in engineering analysis requirement for the critical design review and in the experimentation requirement for the debriefing design review.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies – demonstrated over the course of the project through seeking help from staff, learning project-specific engineering analyses, and the tacit knowledge gained through the process of building the final prototype.

Additional ABET requirements for graduates of mechanical engineering programs include:

1. Knowledge of chemistry and calculus-based physics – *demonstrated through the engineering models requirement and through materials selection for the bill of materials requirement.*
2. Ability to apply advanced mathematics through multivariate calculus and differential equations – *demonstrated in the engineering models and experiments requirements.*
3. Familiarity with statistics and linear algebra – *demonstrated in the engineering models and experiments requirements.*
4. The ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems – *demonstrated through the project completion.*

Further, ABET requires that students must be prepared for engineering practice through the curriculum, culminating in a major design experience based on knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints. These include economic, environmental, sustainability, manufacturability, ethical, health/safety, social, and political standards and/or constraints.

At Yale, MENG 487L/488L is one of the Mechanical Engineering Program's primary methods to address these requirements. These outcomes will be measured through the course and your scores recorded, with your performance evaluated against your peers. We will also ask you to evaluate each other with regard to contributions to the team effort at three points in each semester.

Course Requirements:
The primary requirement of this course is the successful completion and documentation of your team's project. To facilitate the process, and demonstrate fulfilling the educational objectives of the Mechanical Engineering Program, the following deliverables are required.

Team Requirements

Design reviews – Your team will have three design reviews each semester. Each design review will focus on specific achievements necessary for the continuation of the project. Design reviews consist of a presentation and a project binder review. Presentations are graded on a pass-fail basis, and project binder reviews are graded normally. If a team fails a design review presentation, they will be given specific feedback to correct for the next time and another opportunity the following Tuesday or Thursday, whichever comes first. Certain design reviews will also require live prototype demonstrations.

- *Preliminary design review (Fall)* – You will need to describe in detail the project scope (i.e. problem definition, problem statement, technical benchmarks, customer requirements, and engineering specifications), the expected critical functions of your design, a basic business case for your design, a preliminary Gantt chart for the whole project, a preliminary budget, and individual team roles.
- *Conceptual design review (Fall)* – You will need to present any updated information relevant to the prior design review in addition to presenting a summary of the concept generation process, the system architecture diagram, circuit block diagrams, and function diagrams for the selected concept, and a detailed Gantt chart and budget for the remaining project time.
- *Detailed design review (Fall)* – You will need to present any updated information relevant to prior design reviews in addition to detailed engineering analysis, including FMEA, engineering models and experiments for at least all critical functions, CAD models for the full design, circuit schematics, a bill of materials, and customer feedback on the design, if applicable. As before, the Gantt chart and budget should be updated.
- *Subsystem design review (Spring)* – You will need to present any updated information relevant to prior design reviews in addition to functional prototypes of all critical functions and a description of the expected user operation of the final design.
- *Critial design review (Spring)* – You will need to briefly summarize all information from prior design reviews in addition to performing a live demonstration of a fully functional prototype of your final design. You must also present an updated business model, an estimate of manufacturing costs and volumes for your design, and comment on design changes you would make to make it more marketable.

- *Debriefing design review (Spring)* – You will summarize your efforts over the full course for a public audience. In addition, you will need to have improved the aesthetics of your final prototype, finalized all documentation, conducted performance experiments on your prototype, and return all materials in your workspace that are not part of your final prototype.

Project binder – Your team must maintain a project binder that has the following sections:

- **Design documentation** – These documents, which your team will prepare for all assignments requiring written work, will detail various aspects of the design and analysis for the project. This documentation helps others understand your design decisions.
- **Drawings –** CAD, wiring diagrams, and programming flowcharts
- **Presentations –** Slides from the Concept, Prototype and Detailed Design Presentations
- **3-9 reports –** Weekly 3-9 reports

The team binder will be due one week after a successfully passed design review. The team binder will contain all the above documentation and corrections requested during design reviews. The documentation should all be treated as "living documents" and should be updated as the project progresses.

The project binder also serves as the formal report for this course, and each section should include a brief description of its contents.

Weekly design meetings – Your team will meet weekly with the teaching team during the lab period. The purposes of these meetings are to monitor performance, to review the project schedule, and to provide feedback.

Individual Requirements

Individual design notebooks – Your design notebook (or "lab notebook") is a record of your individual contributions to the design process and will be used to evaluate your level of effort on the project. The lab notebook will include your project notes, calculations, and sketches. Also, the lab notebook should catalog contributions to the project in terms of CAD drawings, wiring diagrams, programming notes, and fabricated/procured components. This notebook is effectively your record of the work in progress and has legal ramifications in the "real world." Remember: "If it is not written down, it did not happen." At the end of the course your design notebook must be submitted with the team's Project Binder. Lab notebooks will be reviewed biweekly in lecture.

Individual development – You will be evaluated by the quality of your technical contribution to the team project, and how well you demonstrate your own development as an engineer. This is evaluated primarily in the form of instructor judgement as a result of reported contributions as recorded in the 3-9 reports, peer evaluations, and the final design deliverables.

Grading:
Your course grade will be based on instructor evaluations of your performance in all aspects of the course. For superior performance, you are expected to take ownership for the successful completion of the team project. You must complete assignments on time and ensure the quality of not only your own work but also that of your colleagues. In addition you are expected to contribute to successful coordination of the team effort, maintain effective communication with the Project Advisors, and be recognized as a quality performer by your team members.

Individual contribution

o Individual design notebooks	14%
o Peer reviews	1%
o Instructor judgment (determined based on peer reviews)	10%

Team collaboration

o 3-9 reports	7%
o Design Review Submission (team binder content)	40%
o Physical prototype demonstration	28%

Note: The team grade may be adjusted for an individual student based on their individual performance.

The **course schedule** appears on the next three pages.

Schedule for Mechanical Design: Process and Implementation I and II (MENG 487L/488L)

FALL 2019

MENG 487L	Week of (M)	Lecture Topic	Deliverable in Lab
1	28-Aug	Course Overview, Real-World Design Process, Design Reviews, Documentation?	
2	2-Sep	Design Process Overview, Problem Statements, Problem Definitions, Specifications	
3	9-Sep	Project Planning and Budget	Notebook checks, teaming assignment
4	16-Sep	Design Review	**Preliminary Design Review**
5	23-Sep	Creative Idea Generation and Prototyping	Notebook checks, peer review, design review submissions
6	30-Sep	Evaluating Alternatives and Making Selections	
7	7-Oct	Engineering Safety	Notebook checks and peer evaluation
8	14-Oct	Design Review	**Conceptual Design Review**
9	21-Oct	Real World Design Process (Joe)	Notebook checks, peer review, design review submissions
10	28-Oct	How to Communicate Engineering Modeling and Analysis	
11	4-Nov	Power and Transmission	Notebook checks and peer evaluation

12	11-Nov	Material Properties & Material Selection	NOTE: No purchase orders accepted after this week
13	18-Nov	Extra topics	Notebook checks
15	2-Dec	Design review	**Detailed Design Review**
16	9-Dec	Design review (continued)	Notebook checks, peer review, design review submissions

SPRING 2020

MENG 488L	Date	Lecture Topic	Deliverable in Lab
1	13-Jan	Engineering Ethics / Engineering Standards	
2	20-Jan	Design Review	**Critical Subassembly Review**
3	27-Jan	Patent Process	Notebook checks, peer review, design review submissions
4	3-Feb	Engineering economics and business considerations	
5	10-Feb	No lecture - only team meetings with instructors	Notebook checks NOTE: No purchase orders accepted after this week
6	17-Feb	No lecture - only team meetings with instructors	
7	24-Feb	Design review	**Critical Design Review**

8	3-Mar	No lecture - only team meetings with instructors	Notebook checks, peer review, design review submissions
11	24-Mar	No lecture - only team meetings with instructors	
12	31-Mar	No lecture - only team meetings with instructors	Notebook checks
13	7-Apr	No lecture - only team meetings with instructors	
14	14-Apr	No lecture - only team meetings with instructors	Notebook checks
15	21-Apr	No lecture - only team meetings with instructors	
16	28-Apr	Design review	**Debriefing Design Review**, Notebook checks, peer review, design review submissions

Appendix H – 2020 Survey of Alumni of the Mechanical Engineering Program form 2016 to 2020 (Survey Questions)

Instructions: As part of our ongoing process to improve the Mechanical Engineering Program, we would appreciate your feedback in two key areas. First, we would like to have your assessment as to how we are meeting our Program Educational Objectives. These are listed below. The ratings are on a scale from 0 to 100, where 0 indicates that the Program did not achieve the objective, whereas 100 indicates that the Program did achieve the objective. In addition, we would like you to rate your ability, gained through the Yale Mechanical Engineering program, in each of the ABET outcome categories (1–7). (ABET is the professional organization that accredits undergraduate programs in mechanical engineering, as well as other engineering disciplines.) Please use a scale from 0 (no ability) to 100 (confident). At the bottom of the survey, you can include comments about the strengths of the Program, as well as what can be improved. We appreciate your feedback.

Program Educational Objective 1: To provide a comprehensive introduction to the basic science and mathematics courses that provides the foundation of mechanical engineering.
(Achievement: 0 =Low; 100=High)

Program Educational Objective 2: To provide thorough training in methods of analytical, experimental, and data analysis, including problem formulation
(Achievement: 0=Low; 100=High)

Program Educational Objective 3: To provide the fundamentals of the design process including project innovation, synthesis, and management both individually and in a team setting.
(Achievement: 0=Low; 100=High)

Program Educational Objective 4: To provide both technical and nontechnical programs that develop strong oral and written communication skills.
(Achievement: 0=Low; 100=High)

Program Educational Objective 5: To instill in our students an understanding of their professional and ethical responsibilities that impact society and their profession.
(Achievement: 0=Low; 100=High)

(continued)

ABET Outcome 1: I have an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 2: I have an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 3: I have an ability to communicate effectively with a range of audiences.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 4: I have an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 5: I have an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 6: I have an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
(Ability: 0=No ability; 100=Significant ability)

ABET Outcome 7: I have an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
(Ability: 0=No ability; 100=Significant ability)

Comments: Please provide particular strengths of the Mechanical Engineering Program, as well as provide ideas for improvement.

Signature Attesting to Compliance

By signing below, I attest to the following:

That Yale's Mechanical Engineering Program has conducted an honest assessment of compliance and has provided a complete and accurate disclosure of timely information regarding compliance with ABET's Criteria for Accrediting Applied Science Programs to include the General Criteria and any applicable Program Criteria, and the ABET Accreditation Policy and Procedure Manual.

Jeffrey F. Brock

________________________________ **July 31, 2020**