ABET
Self-Study Report

for the

Bachelor of Science Degree in Electrical Engineering

at

Yale University

New Haven, CT

August 1, 2020

CONFIDENTIAL

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A. Contact Information

Leandros Tassiulas
Department Chair
John C. Malone Professor of Electrical Engineering
Degrees: Ph.D.
Room / Office: 336
Office Address:
17 Hillhouse Ave
New Haven, CT 06511
Mailing Address:
P.O. Box 208284
New Haven, CT 06520
Phone: (203) 436-5965
Email: leandros.tassiulas@yale.edu

Mark Reed
Director of Undergraduate Studies
Harold D. Hodgkinson Professor of
Electrical Engineering
Degrees: Ph.D.
Room / Office: 523
Office Address:
Becton Engineering Center
15 Prospect Street New
Haven, CT 06511 Mailing
Address:
P.O. Box 208286
New Haven, CT 06520
Phone: (203) 432-4306
Email: mark.reed@yale.edu

B. Program History

Instruction in engineering at Yale was given in the Sheffield Scientific School, started in 1852, making it one of the oldest engineering programs in the U.S. 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.

The last General Program Review was in 2014. The Program was reaccredited following this review.

Major changes to Yale Engineering since 2014:

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

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

- 2017: The Linda and Glenn H. Greenberg Engineering Teaching Concourse, comprised of eight new undergraduate teaching labs, storage area and a lab administrative office, opened to co-locate lab instruction for all engineering programs. The new labs were designed and are operated to maximize flexibility in the space, where each lab 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 stored in adjacent laboratory preparation rooms when not being used.

  At the end of the year, Dean Kyle Vanderlick concluded 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. She also created the Yale Center for Engineering Innovation & Design and secured the stability of the space with $23 million support from SEAS alum Dr. James S. Tyler. The Greenberg Engineering Concourse was also completed under the leadership of Dean Vanderlick. She also 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 was 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, was published and 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 Jeffery Brock was 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, serves 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 began on the Tsai Center for Innovative Thinking at Yale (Tsai CITY), a 12,500 square foot building adjoining the Center for Engineering Innovation and Design. 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, 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 was appointed as Yale's Provost, replacing Professor Ben Polak who served as Yale's Provost from 2012-2019. Provost Strobel, the Henry Ford II Professor of Molecular Biophysics and Biochemistry, 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.

C. Options

Four undergraduate degrees are offered in the Department:
- B.S. in Electrical Engineering (ABET Accredited)
- B.S. in Electrical Engineering and Computer Science
- B.S. in Engineering Sciences (Electrical)
- B.A. in Engineering Sciences (Electrical)

Three undergraduate degrees are offered:
- M.S. in Engineering & Applied Science
- M.Phil. in Engineering & Applied Science
- Ph.D. in Engineering & Applied Science

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

D. Program Delivery Modes

The undergraduate Electrical Engineering program is offered during the day.

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

Program Concerns

The 2014 ABET Final Statement identified “Criterion 6: Students” as a concern. The statement included the following:

> “Criterion 6. Curriculum This criterion requires that students be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. The program has been successful in providing a high-quality culminating design experience for the students to date. However, the selection of some design projects has not been made until several weeks into the semester thus reducing the amount of time available to students to complete design work. While this criterion is currently met through the dedication and hard work of faculty and students, there is a risk that some elements of the design projects may be compromised by the limited amount of work time. Without earlier selection of all capstone design projects future compliance with this criterion may be jeopardized.”

The program did not provide a response to this shortcoming during the due process period, and it remained unresolved in the 2014 ABET Final Statement. In response to this concern and other factors, the department has amended the project selection process in capstone design to allow students the entire term to immediately work the designed solutions, fabrications, testing and product integration associated with each project.

GENERAL CRITERIA

CRITERION 1. STUDENTS

A. Student Admissions

All undergraduate students are admitted through Yale College and are free to select any program of study, including engineering. The Admissions Office examines yearly 38,000+ applications to form a class of approximately 1,500 students, as given in Table 1-1. Admissions looks for academic ability and achievement combined with such strengths as motivation, curiosity, energy, and leadership ability. No simple profile of grades, scores and activities guarantees admission. In recent years, over 300 students expressing an interest in engineering have been admitted, and slightly over half matriculate to yield approximately 175 freshmen interested in engineering. Freshmen are regularly admitted with advanced standing in a few subjects including Chemistry, English, Mathematics and Physics. Such students usually start in advanced courses in these subjects, and often take introductory engineering courses in their first year. Freshmen 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

B. Evaluating Student Performance

The requirements for the bachelor's degree from Yale College are thirty-six course credits, the fulfillment of the distributional requirements, including the foreign language requirement, and the completion of a major program. The distributional requirements are intended to assure that all Yale College graduates have a background in the humanities and arts, sciences, social sciences, foreign language, quantitative reasoning, and written communications. Additional program-specific courses are required to obtain the BS degree in Electrical Engineering.

Course credits and the distributional requirements are supervised by the Registrar's Office, the residential college deans, and the Yale College Dean's Office. The Director of Undergraduate Studies (DUS) in the Department of Electrical Engineering is responsible to certify to the registrar that seniors have completed the requirements of the major program. 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. No senior graduates until the DUS has certified that he or she has fulfilled the requirements of the major program. It should be noted, first of all, that the procedures for such certification are different at the end of the fall term from what they are at the end of the spring term.

Fall Certification

Seniors who complete 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 academic records of these seniors, showing all their courses and grades up through the fall term just completed, are sent to the DUS. Upon receiving these academic records, 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 (departmental examination, senior essay, or project).

Spring Certification

Because of the time pressure before graduation, this certification occurs in two steps in the spring: (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 what is called 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 of all seniors in the major who are finishing their degree requirements in that term.

In addition to the Provisional MC List, the DUS is asked to complete a Major Completion form for each student. On this form, which shows all of the courses in which the student is enrolled, the DUS will be asked to circle the specific courses that the student needs to complete in order to graduate. If the student needs any 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. These come twice: 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.

A final task for the DUS, right after the Spring terms grades for seniors become available, is the identification of seniors warranting “Distinction in the Major.” The criteria are set by Yale College regulations and involve the number of courses in the major with grades of A and A-, said number dependent on whether the Senior Project grade is A or A-, or lower.

In addition to this monitoring, the DUS also reviews each student's record to assure that the prerequisite courses are being taken. If the prerequisite courses are not being met, the DUS does not allow the student to continue in the ABET program and notifies the student that they must consider one of the other non-ABET programs.

C. Transfer Students and Transfer Courses

Yale College welcomes a small number of transfer students each year. 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.

As competitive as the admissions process is for freshmen, the transfer process is even more so. Yale receives more than 1,000 transfer applications each year, and we have 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 3.8. Given the competitive nature of the transfer admissions process, candidates should have compelling reasons for attending Yale and should think carefully about whether Yale is the right fit for them before making the effort to complete an application.

The Admissions Committee meets once a 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. 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 8 credits that total consisting 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 should consult carefully with their residential college deans in order to ascertain their status with regard to the distributional requirements, especially the foreign language requirement.
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. Students who must remain at Yale beyond the terms designated in the final evaluation of transfer credits must petition the Yale College Committee on Honors and Academic Standing for permission to do so. Such a petition will be considered only if it is impossible for the student to complete the requirements for the bachelor's degree in the designated number of terms. A student thus granted permission to remain at Yale for an additional term, if the term represents more than the equivalent of eight terms of enrollment at the college level, is not eligible for scholarship

assistance from Yale for the additional term, although other forms of financial aid may be available.

5. 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. A transfer student who needs a record of studies completed before admission to Yale must secure a transcript from the previous institution.
6. 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. An exception is made for transfer students who earn credit on a Junior Year or Term Abroad. Transfer students may attend a Junior Year or Term Abroad if they enroll in Yale College proper for at least four terms, earning by attendance at Yale a minimum of eighteen course credits.
7. Transfer students are not bound by the distributional requirement for the first two years, but they must fulfill the distributional requirements for the bachelor's degree. See paragraph 1 above. Based on stipulated scores earned on Advanced Placement tests taken in secondary schools, transfer students may fulfill the foreign language requirement. They are not eligible for the award of acceleration credit or for acceleration by use of acceleration credits.
8. Once a student has been accepted for admission as a transfer student, the student may not attend Yale as a special student before his or her first term of enrollment at Yale.

Credit Transfer – Under the conditions described below, 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. Forms on which to request the award of credit for study that has been completed elsewhere are available at the offices of the residential college deans. Before undertaking such outside study, the student should consult the residential college dean both about the institution to be attended and the course to be taken there. Courses in the Yale Summer Programs, including the Yale Summer Language Institute, 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. Similarly, courses taken at the Yale Program at the Paul Mellon Centre in London are Yale courses and do not count as outside credit. Note that credits earned outside Yale may not be used to reduce the expected number of terms of enrollment in Yale College. In order for credit to be given for courses taken elsewhere, all of the following conditions must be met:

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

(b) A student who has studied at an American University, or abroad on 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, then the student must furnish an official certificate of enrollment, showing if possible the course or courses completed.

(c) 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.

(d) 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.

(e) 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.

(f) 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.

(g) 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

Yale's undergraduate students receive career and academic guidance from a few individuals. This large group of individuals serves as a constellation of advisers who assist Yale undergrads. The advisers help students navigate the academic and other developmental aspects of life at Yale College.

Each undergraduate program at Yale is advised by a Director of Undergraduate Studies (DUS). Directors of Undergraduate Studies are authorities on the nature and objectives of their disciplines and the general features of the undergraduate program. More particularly, the DUS is familiar with the range, focus, and objectives of individual courses of the program, as well as with placement policies and major requirements. Prof. Reed has been the Director of Undergraduate Studies for Electrical Engineering since 2015.

While the DUS has primary responsibility for each student's academic progression, a host of other advisers also assist Yale undergraduates. Much of this additional guidance is organized around the specific Residential College where each student lives during their four years at Yale.

The First-year Counselor is a senior who 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. As seniors, First-year Counselors 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 first year. 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. Students are encouraged to discuss with their 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 comes after a careful discussion of the student's course of study.

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 Residential College Dean administers the academic regulations and oversees freshman 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. For these reasons and others, the Dean is crucial to academic life at Yale.

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 COVID19 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.

Each student in the Electrical Engineering major meets with the DUS during the shopping period at the start of each semester to obtain course approval required by the registrar. The small number of EE majors allows the DUS to know each one individually. During these meetings, the DUS chats informally with the student to determine if there are any academic or personal problems the student may have and means to address these. Athletes and ROTC students often have scheduling difficulties that can be resolved by accommodations with the instructor. These meetings also often lead to suggestions for the student to meet with EE faculty who have similar interests and who can provide career advice.

E. Work in Lieu of Courses

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

F. 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", which is annually published.

Prerequisites: The BS in EE degree requires MATH 112, 115, ENAS 151 or MATH 120 or higher, ENAS 130 or higher, and PHYS 180, 181 or higher. Students whose preparation exceeds the level of ENAS 151 or MATH 120 are asked to take a higher-level mathematics course instead, such as MATH 250. Similarly, students whose preparation at entrance exceeds the level of PHYS 180, 181 are asked to take higher-level physics courses instead, such as PHYS 200, 201. Students whose programming skills exceed the level of ENAS 130 are asked to take a more advanced programming course instead, such as CPSC 201.

Required courses: The BS in Electrical Engineering requires, beyond the prerequisites, four term courses in mathematics and science and thirteen term courses in topics in engineering. These courses include:

1. Mathematics and basic science (four term courses): ENAS 194; MATH 222 or 225; APHY 322 or equivalent; S&SD 241 (Statistics & Data Science 241), or equivalent.

2. Electrical engineering and related subjects (thirteen term courses): EENG200, 201, 202, 203, 310, 320, 325, 348, 481 (the senior project); and four engineering electives, at least three of which should be at the 400 level. MENG 390, CPSC 365, and selected 400-level Computer Science courses qualify as ABET electives.

Each student's program must be approved by the DUS. At the completion of the program, the major completion (MC) form indicates the courses that are required for the BS in Electrical Engineering. The registrar verifies that the student has achieved a passing grade in each required course. If all the required courses have not been taken, the student graduates with one of the non-ABET accredited degrees. If the requirements of Yale College are not met, the student is not granted a Yale degree. In this case, students are required to take additional courses until the requirements for a program are met.

For students who have taken the equivalent of one year of calculus in high school, a typical ABET-accredited B.S. program might include:

Freshman	**Sophomore**	**Junior**	**Senior**
EENG 200	CPSC112 or ENAS130	APHY 322	EENG 481
EENG 201	EENG 202	EENG 310	Four electives
ENAS151 or MATH 120	EENG 203	EENG 320	
MATH 222	ENAS 194	EENG 325	
PHYS 180	STAT 241	EENG 348	
PHYS 181			

For students who start with MATH 112, a typical ABET-accredited B.S. program might include the following (this group is atypical and often such students take math courses in the summer to lighten the load during the academic year):

Freshman	**Sophomore**	**Junior**	**Senior**
CPSC 112	EENG 200	EENG 202	APHY 322
EENG 201	ENAS 151 or	EENG 203	EENG 481

	MATH 120		
MATH 112	ENAS 194	EENG 310	S&DS 241
MATH 115	MATH 222	EENG 320	Four electives
	PHYS 180	EENG 325	
	PHYS 181	EENG 348	

G. Transcripts of Recent Graduates

Transcripts of student graduating the ABET-accredited B.S. degree in Electrical Engineering indicate the degree as "*Bachelor of Science in Electrical Engineering"* and contain the phrase "*Satisfied the criterion for the ABET-accredited degree."*

Transcripts of recent ABET-program graduates will be provided when requested by the team chair.

H. Quantity and Quality of ABET-accredited EE graduates at Yale

The ABET-accredited EE program at Yale differs from that at most other engineering educational institutions in terms of the number of graduates and their caliber.

Because of our programmatic structure, students who are having difficulties meeting the stringent requirements of the ABET-accredited program - or simply have their own PEO that is sufficiently different from our ABET PEOs - often choose or are advised to switch to one of our three other non-ABET programs that are less intensive. For example, the instructor of ABET capstone project course (R. Kuc) did not allow a mediocre student, based on an assessment of his performance in prerequisite courses, to take the EENG481 capstone project, thus preventing him from graduating with an ABET-accredited degree. Because of this availability of alternate programs in EE, the number of graduates of the ABET-accredited EE program is typically the smallest. By contrast, most other engineering schools offer only the ABET-accredited program EE degree.

The few students that do complete the ABET-accredited EE program are typically the most industrious. Because these students have survived the highly-selective Yale admissions process, they have excelled before coming to Yale and the EE faculty take a personal interest in helping them continue to excel in achieving their chosen EE-PEO.

Of special note, in the past four years nearly half of our ABET-accredited EE graduates are women This is a quantitative trend that gratifies the program.

In this Self Study this small number of ABET-accredited graduates necessitates a combination of quantitative and qualitative means for assessing PEOs and outcomes. In summary, the EE faculty believes that this Self Study will demonstrate a program that matches the exceptional quality of our students.

CRITERION 2. PROGRAM EDUCATIONAL OBJECTIVES

A. Mission Statement

Mission of the University – Established in 1701, Yale University is one of the premier institutions of higher education in the United States. 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:

> **YALE'S MISSION STATEMENT:** As one of the world's leading centers for learning, Yale's primary mission is to attract, educate and motivate a diverse group of the most highly talented men and women in order to advance and disseminate knowledge and to promote the scholarship, high character, values, and leadership which can be directed towards sustaining and improving society. Intrinsic to this mission are the faculty's dual responsibilities for outstanding teaching and original research, carried out in a community comprised of Yale College, a Graduate School with broad coverage of the arts and sciences, and an array of professional schools in arts, sciences, and learned professions. This mission requires a continuing commitment to the excellence, the competitive position and the reputation for academic leadership that Yale has earned over three centuries.

B. Program Educational Objectives

The following EE Program Educational Objectives (EE-PEOs) were reviewed most recently at a 2019 meeting of the EE faculty, discussed and approved by unanimous vote.

- Academic path – Yale EE graduates will be at a top-tier graduate program conducting research with broad application or significant consequences, with an intention of applying to a quality academic or research institution.

- Industrial path – Yale EE graduates will be in a managerial or policy-making position that provides significant value to the company.

- Entrepreneurial path – Yale EE graduates will bring a broad knowledge to a startup company to deliver a device that meets societal needs.

- Non-traditional engineering path – Yale EE graduates will be completing a professional (Business, Law, Medicine) program and joining a top-level firm in which to apply engineering knowledge gained at Yale.

The EE-PEOs are published in hardcopy and online in the *Yale College Programs of Study* (*YCPS)*. These objectives are also posted on the EE Department's webpage

http://seas.yale.edu/departments/electrical-engineering/undergraduate-study

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

The mission of Yale University fundamentally states *to advance and disseminate knowledge and to promote the scholarship, high character, values, and leadership which can be directed towards sustaining and improving society*. The EE-PEOs project Yale's mission on to the main professional aspirations that our ABET-Program graduates have and the recruiters of our graduates desire. All EE-PEOs contribute toward improving society by our graduates having the engineering education to model technical and non-technical problems in society using quantitative means and applying the problem-solving skills learned in the EE Program to find solutions. The EE-PEOs urge our students to aspire to join top-tier academic, industrial or professional institutions, or start their own company, to maximize the impact of their Yale EE education.

D. *Program Constituencies*

The main constituencies of the program include the following four main categories.

1. EE majors in the ABET program.
2. EE Faculty, who must balance teaching and research activities, as mentioned explicitly in Yale's Mission Statement.
3. Alumni, who want the value of their Yale Engineering degree to be maintained and enhanced over time.
4. Recruiters, who employ our students and want them to be maximally productive from the time they join the company.

E. *Process for Review of the EE-PEOs*

The PEOs are reviewed using the following processes for the respective constituencies.

1. ABET EE majors. There are two processes for the EE ABET majors: by the DUS and by the Instructor of *EENG 481 Advanced ABET projects.*

   Students entering the EE ABET program are aware of the published PEOs. The DUS meets with EE ABET students at the beginning of each term to discuss their plans and career aspirations. Most student goals typically fit into one of the PEOs, and when it does not, the issue is addressed and discussed at an EE faculty meeting to determine if this represents a trend.

   In *EENG481* the recent enrollment has typically numbered approximately 6 seniors. During the course, the Instructor gets to know each student individually and their career options are discussed. This helps to hone their project to give the student experience in their desired career. The discussion usually starts with a review of the EE-PEOs and their adequacy to meet their needs.

2. EE Faculty. The students can participate in faculty research projects by taking advanced special projects courses (Advanced Special Projects EENG471, EENG472) in their junior and senior years. Occasionally, motivated freshman and sophomores take half-credit special project courses (Special Projects EENG235, EENG236) to explore and extend their technical interests.

3. Alumni. The Yale Science and Engineering Association (YSEA) is a loyal and dedicated alumni group that supports and nurtures undergraduate research and engineering-based extracurricular activities. The YSEA sponsors undergraduate student projects and technical presentations. During these visits, the faculty gathers their input as to career opportunities and trends that should modify the EE-PEOs. This input is discussed at EE faculty meetings in order to make the EE-PEOs current and attractive to potential EE majors.

4. Recruiters. Typically, Yale graduates are in high demand, and companies, such as Microsoft, Google, and Boeing, which recruit from Yale, send their employees who are Yale engineering alumni to interview potential hires. When these alumni return to Yale they meet with the DUS and former professors to discuss the adequacy of the EE-PEOs

In summary, this process has maintained a general set of EE-PEOs that give incoming majors an idea of what careers can await them as an ABET-EE graduate. The most recent change in the EE-PEOs came from a small number of our seniors who embarked on a career with start-up companies. This led to a slight change to the Entrepreneurial path to explicitly mention start-up companies.

CRITERION 3. STUDENT OUTCOMES

A. Student Outcomes

The Department of Electrical Engineering adopted the ABET student outcomes for the ABET-accredited program.

Upon graduation, each graduate of an ABET-accredited BS EE degree must have demonstrated competence in each of the following seven outcomes.

(1) An ability to identify, formulate, and 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 together provide leadership, create a 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.

These outcomes are published on the Department's webpage http://seas.yale.edu/departments/electrical-engineering/undergraduate-study.

B. Relationship of Student Outcomes to Program Educational Objectives

To simplify the description of the relationships of the EE-PEOs to the student outcomes, we label the four EE-PEOs with the following notation that is employed in Table 3-B-1, which describes how the student outcomes prepare graduates to attain the program educational objectives.

EE-PEO 1: Academic path – Yale EE graduates will be at a top-tier graduate program conducting research with broad application or significant consequences, with an intention of applying to a quality academic or research institution following graduate school.

EE-PEO 2: Industrial path – Yale EE graduates will be in a managerial or policy-making position that provides significant value to the company.

EE-PEO 3: Entrepreneurial path – Yale EE graduates will bring a broad knowledge to a startup company to deliver a device that meets societal needs.

EE-PEO 4: Non-traditional engineering path – Yale EE graduates will be completing a professional (Business, Law, Medicine) program and joining a top-level firm in which to apply engineering knowledge gained at Yale.

Table 3-B-1. Relationship of Student Outcomes to Program Educational Objectives

Outcome	EE-PEO 1	EE-PEO 2	EE-PEO 3	EE-PEO 4
1	Provides excellent theoretical preparation for a grad program	Quantitative reasoning is important for managerial skills	Fundamentals lead to the next breakthrough device	Quantitative reasoning is helpful in these fields
2	Helps student recognize important problems	Helps manager choose projects to pursue	Helps in choosing a successful product	Provides appreciation of a well-designed product in their field
3	Prepares grad to present and publish results	Helps manager communicate with upper-management and with a work group	Helps owner sell a device to investors	Helps explain arguments in a logical manner
4	Defines research integrity	Helps manager instill ethical environment	Helps owner instill ethics into company	Ensures awareness of the need for ethical practices
5	Recognizes the responsibilities of being in a research group	Recognizes the responsibilities of subordinates	Recognizes the responsibilities of a company team	Recognizes the operation of an organization
6	Provides excellent preparation for grad program	Knowing the design process informs management decisions	Knowing the design process helps in product development	Data interpretation is crucial in these fields
7	Helps keep up with the latest research results from other labs	Helps keep up with the latest products	Helps keep up with the latest devices	Helps keep professionally current

C. Process for the Establishment and Revision of the Student Outcomes

The ABET 1-7 outcomes have been accepted by the EE faculty for the ABET program by consensus. Student outcomes are reviewed by the faculty at the beginning and end of each academic year when preparing and assessing outcome achievement in their courses.

Because the ABET outcomes are well-established, generally accepted, understood by our constituents, work well in practice, and are more concise than the previous (a)-(k) ABET outcomes, the EE faculty has not sought to add to them.

Having polled our constituents **-** (EE faculty in meetings, students during advising, recruiters during visits, and recent graduates during visits and emails) – there is no evidence that our current student outcomes need to be revised. Preparing the table above helps clarify some of the less-obvious relationships between the outcomes and EE-PEOs that will be used in future faculty meetings.

Table 3-C-1 indicates outcomes that are demonstrated by student work in each ABET-EE required course. It shows most instructors attempt to have students demonstrate outcome achievements in most outcomes to one degree or another. The degrees are shown in the SEAS ABET grading sheets and in the short ABET forms for each course, described in the next chapter.

Table 3-C-1 Outcomes demonstrated by student work in ABET-EE required courses.

	ABET Outcome						
EENG Course	1	2	3	4	5	6	7
200	X	X		X	X	X	X
201	X	X	X		X	X	X
202	X	X					
203	X	X	X	X		X	X
310	X	X		X			
320	X	X	X	X	X	X	X
325	X	X	X	X	X	X	X
348	X	X	X	X		X	X
481	X	X	X	X	X	X	X

D. Enabled Student Characteristics

Table 3-D-1 indicates how each outcome is applied to graduates in the EE-ABET program through performance criteria (PC) established by the EE faculty. The table also includes the required courses in the EE-ABET program curriculum that enables each outcome, including the rubrics for each PC. These rubrics are used to assess each outcome using the student homework and tests in each course.

Table 3-D-1 Performance criteria with rubrics for each outcome.

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

Performance Criterion	Unsatisfactory (1-2)	Acceptable (3-4)	Exemplary (5)
Calculus EE200 EE202 EE320 AP322 EE481	Evaluates only simple integrals, does not know what integral to apply	Applies and evaluates most integrals using tables. Uses MATLAB for approximating	Understands limitations and evaluates all integrals with tables or Mathematica or numerically with MATLAB
Differential equations AP322 EE201 EE320	Solves only simple Dif Eq does not know how to set up a Dif Eq	Solves most Dif Eq using more than method	Formulates and applies Dif Eq to novel systems
Linear algebra EE202 EE310 EE481	Unsure of how and when to use matrix formulation	Comfortable with matrices and their manipulation	Applies linear algebra to novel problems and for optimizing system design
Laplace Transforms EE202 EE310	Uses only software programs	Takes advantage of branch cuts to solve problems	Inverts Laplace transform using complex function methods
Probability & Statistics S&DS241 EE481	Minimal grasp statistical arguments	Applies statistics to most problems and issues of noise	Understands how and when to apply statistics to practical system implementations
Physics EE200 EE320 AP322	Not confident with applying scientific principles to eng systems	Applies physical principles to systems	Understands limitations of ideal systems and can correct for actual systems
Electromagnetism AP322 EE203	Not facile with Maxwell’s Eqs	Applies Maxwell’s Eqs to standard problems	Applies Maxwell’s Eqs to novel devices
Fourier analysis EE202 EE310	Cannot evaluate integral of simple function or evaluate DFT with MATLAB	Can evaluate integral or the DFT and understand magnitude and phase	Interpreted and analyzed results in a distinguished manner

Table 3-D-1 (Continued)

(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 (1-2)	Acceptable (3-4)	Exemplary (5)
Create a hypothesis EE203 EE320 EE325 EE348 EE481	Lacks knowledge of the experiment	Knows fundamental principles tested	Has thorough knowledge and tries novel alternative ideas
State what is to be shown EE203 EE325 EE348 EE481	Confused and not sure, makes repeated mistakes	Follows instructions to the letter	Tries novel approaches
Use test equipment EE200 EE203 EE320 EE325 EE481	Sufficient knowledge so as not to get hurt or cause harm or damage	Understands how to use equipment for a circuit or experiment	Can measure novel features beyond what was asked
Circuit analysis EE200 EE203 EE320 EE325 EE481	Poor knowledge of circuit principles and techniques	Applies correct circuit techniques to standard problems	Understands and can analyze complicated circuits
Laboratory techniques and understanding EE200 EE203 EE320 EE325 EE481	Has trouble performing laboratories, write-ups and reports are cursory	Most experiments work, write-ups are sufficiently descriptive	Thorough write-ups and detailed data analysis from digital oscilloscopes connected to the Web

Table 3-D-1 (Continued)

(3) An ability to communicate effectively with a range of audiences

Performance Criterion	Unsatisfactory (1-2)	Acceptable (3-4)	Exemplary (5)
Summarize technical topics EE325 EE348 EE481	Unfamiliar with fundamental terms	Uses conventional jargon	Understands audience and adjusts technical level
Present and discuss technical concepts EE203 EE325 EE348 EE481	Unsure of results and terminology	Clearly explains what was done	Describes fundamental limitations and state of the art
Multi-media use EE348 EE481	Uses only Word processing with limited images and MATLAB plots	Word, Powerpoint, MATLAB plots and animations	Also, includes videos that are relevant to the explanation
Makes problem understandable ENAS130 EE348 EE481	Little interpretation of required tasks and required characteristics of the design	Basic understanding of problem, of the preliminary solution and explanation of results	Solid overview of design choices and experimental data

Table 3-D-1 (Continued)

(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 (1-2)	Acceptable (3-4)	Exemplary (5)
Yale's Distributional Requirements DUS	Takes simple, non-challenging courses having little relationship to engineering profession	Takes majority of courses that relate to engineering	Takes challenging courses that prepares student to be a leader in technology
Interaction with non-technical teams DUS	Engineering-only interests	Broader interests	Leader in non-technical activities
Apply concepts to system design EE481	Unaware of social and ethical impact of system	Considers evident safety issues in a design	Explores broader social, safety and ethical impacts of design

(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 (1-2)	Acceptable (3-4)	Exemplary (5)
Research and gather information EE203 EE325 EE348 EE481	Does not adequately prepare	Used obvious sources	Used appropriate combination of library and Internet sources
Responds to others' input EE481	Discouraged conversations about alternatives	Considered options proposed by teammates	Led discussion while being sensitive to suggestions of others
Knowledge in area of responsibility EE481	Requires others to fill gaps	Sufficient to answer most questions and do the design	Expert in area, optimizes the component performance

Table 3-D-1 (Continued)

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

Performance Criterion	Unsatisfactory (1-2)	Acceptable (3-4)	Exemplary (5)
Research and gather information EE203 EE325 EE348 EE481	Does not adequately prepare before initiating design	Some thought given to final product and employed obvious sources and references	Used appropriate combination of library and Internet resources along with discussions with faculty
Completed design EE203 EE325 EE348 EE481	Design accomplished only half of what was proposed	Implemented proposed functions without any changes	Design was modified to incorporate data results leading to an optimized system
Project report EE348 EE481	Report is limited in scope, contains typos, mostly spec sheets, and program listings (clearly not proof-read)	Polished report that describes design process and result, includes ethical and professional issues	Professional report that describes impact of design, its limitations, and possible future directions
Specify problem mathematically EE203 EE310 EE325	Little interpretation of the required tasks and of the required characteristics of the design	Introductory understanding of problem, of the preliminary solution, and explanation of results	Solid introductory overview, explains design choices and clearly explains impact of experimental data
Apply technical understanding to problems EE320 EE325 EE481	Can solve few problems, understanding clearly not evident	Is able to solve the majority of problems	Solves all problems with few mistakes, detailed and logical formulation
Laboratory techniques EE203 EE320 EE481	Has trouble performing laboratories, write-ups cursory	Most experiments work, write-ups descriptive	Thorough write-ups and detailed data analysis

Table 3-D-1 (Continued)

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

Performance Criterion	Unsatisfactory (1-2)	Acceptable (3-4)	Exemplary (5)
References current literature and device specifications EE348 EE481	Uses only information provided by instructor	References at least one journal article, data sheet, or reliable Internet source that supplements given material	Understands relevance of new information and uses most recent datasheets and references, effective use of Web search tools
Uses modern software tools EE201 EE202 EE203 EE310 EE325 EE348 EE481	Uses MS Office but weak when using engineering software, requires significant help from Instructor and TA	Knows what software exists and uses in design. Discovers features not taught in class that simplify the design process.	Uses a variety of tools and selects those best suited for the task. Seeks information on the Web for solving similar problems.
Applies software tools to current technology EE201 EE310 EE481	Does not understand how evolving software can ease problem solution	Demonstrates skill in MATLAB and Simulink	Mastery of MATLAB and Simulink to model current technology
Uses specifications and standards in system design EE203 EE325 EE348 EE481	Can find specs and standards on the Internet but does not know how to apply them to the design	Uses specs and standards in system design	Understands the limitations of specs and standards in system design

CRITERION 4. CONTINUOUS IMPROVEMENT

A. Student Outcomes

1. *Outcomes Assessment*

The ABET-EE program uses a variety of assessment processes to determine the extent to which outcomes are attained. Three assessment processes that are appropriate for the current size of the EE faculty and number of ABET-EE Program majors include the following.

I. Quantitative Direct Outcome Assessment Processes.
II. Qualitative Direct Outcome Assessment Processes.
III. Indirect Outcome Assessment Processes.

I. Quantitative Direct Outcome Assessment Processes.

The three quantitative direct assessment processes employed are listed in Table 4-1.

Table 4-1: Direct Quantitative Outcome Assessment Processes

Process	Frequency	Assessor	Expected level of attainment	Results	Documentation
1.Detailed outcome assessment in each course	Each course at least once every 6 years + yearly for EE481	Instructor	At least $\geq$3 for all students for all outcomes	$\geq$3 (acceptable) for all outcomes	SEAS ABET grading spreadsheet (SAGS)
2.Outcome attainment and continuous improvement	Every two years	Instructor	All students achieve satisfactory attainment in outcomes covered in course	Most students achieve all outcomes in course. Outcomes not achieved by all modify the next course offering	Short ABET form
3.Assessment of capstone project	Yearly	Instructor and DUS	At least $\geq$3 for all students for all outcomes with some attaining the max level (5)	$\geq$3 for all outcomes	Capstone project report assessment sheet

The table columns describe the following:

- The frequency indicates how often this process is conducted.
- The assessors participating in the process typically include the course Instructor. The DUS also receives the ABET-EE student reports.
- The expected level of attainment for the ABET-EE program is that all ABET-EE Program students attain at least an acceptable level ($\geq$3 on Likert scale) in each outcome by graduation.

Most ABET-EE graduates typically exceed the acceptable level for most outcomes. An assessment for any student for any outcome that falls below the acceptable level triggers an analysis – typically resulting in a corrective action – in a discussion with the Department Chair and/or Instructor initiated by the DUS.

- The results are a summary of the findings for each process, described below. They indicate that all our EE Program seniors have achieved at least acceptable levels of achievement in all outcomes. While ABET-EE students typically exceed the expected level of attainment, a result less than the expected level triggers a DUS action. For example, one student with outcome assessments less than acceptable in several required courses was not allowed to register for EENG481, thus preventing him from graduating with the ABET-accredited BS degree.
- The documentation from each method is listed and will be available for the ABET reviewer upon request.

The table rows give the following processes that give direct quantitative outcome assessments:

1. The detailed outcome assessment in each course is accomplished with the SEAS Grading spreadsheet. The quality of the EE-ABET students and their small number, along with the biannual Short ABET form (process 3), make a once in 6 year assessment sufficient. The SEAS ABET Grading spreadsheet (SAGS) for EENG 481 is completed by the instructor each year and the results are reported to the EE faculty to provide feedback regarding the level of outcome attainment for the program.
2. The assessment of capstone project report is a summary of the SAGS along with a min/max analysis, given below. Using the maximum and minimum scores in assessing outcomes provides a process for continual program improvement. Clearly, outcomes that are assessed as not being Acceptable (having scores <3) trigger mechanisms for closer examination for their alleviation. A maximum level in an outcome that scores less than a 5 indicates that none of our students have attained the exemplary level. This result is atypical for our students and also triggers a closer examination for the cause. Examples are given below.
3. The short ABET form gives a biannual review performed by all instructors of ABET-EE required courses. This form, shown below, contains quantitative data that summaries that given on the SAGS, but it is easier to complete and keeps the faculty *primed* for the ABET process.

The explanation and motivation for each process follows.

I-1. Detailed outcome assessment in each course.

This process uses a common spreadsheet (SEAS ABET Grading spreadsheet - SAGS) that has been adopted by the Yale SEAS ABET-accredited programs for assessing the outcomes in each required course. Figure 4-1 shows the completed SAGS for EENG320.

YALE SCHOOL OF ENGINEERING AND APPLIED SCIENCE

ELECTRICAL ENGINEERING ABET OUTCOME REVIEW

This spread sheet 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
2. An ability to apply engineering design to produce solutions that meet specified needs
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
5. An ability to function effectively on a team and interpret data, and use engineering judgment to draw conclusions
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.

Outcome Rubrics:

Examplary (A): Mastery in energy bands, charge carrier distributions and dynamics, Fermi distribution, p-n junction electrostatics/CV/IV IV, bipolar and field-effect transistors, LEDs. Able to extend ideas taught in class to novel problems presented on tests and homework. Mastery of labratory techniques and analysis.
Very Good (B): Understands concepts of energy bands, charge carrier distributions and dynamics, Fermi distribution, p-n junction electrostatics/CV/IVIV, bipolar and field-effect transistors, LEDs. Competence in labratory techniques and analysis.
Adequate (C): Understands some concepts of energy bands, charge carrier distributions and dynamics, Fermi distribution, p-n junction electrostatics/CV/IVIV, bipolar and field-effect transistors, LEDs. Adequate performence in labratory techniques and analysis.

Improvements from previous or for next course offering:

Previous: 1. Labs were restructured to aligned better with material; 2. revisions of BJT and heterojunction material for clarity

Future: Students had difficulty with lab 4: redo with TS, compare to student's labs

Course Number: EENG 320
Course Name: Introduction to Semiconductor Devices

Student (Y/N), U for undeclared	Student Name	Pset1	Pset2	Pset3	Pset4	Pset5	Pset6	Pset7	Pset8	Pset9	Lab 1	Lab 2	Lab 3&4	Lab 5	Midterm	Final	Assigned Grade	Overall Percent
	points per assignment	100	60	60	70	50	60	50	80	30	10	10	10	10	100	100		100.0
Y		100	60	60	70	50	60	50	76	30	9	9.4	9.4	9.4	100	86	A	95.5
N		100	60	60	70	50	60	48	80	30	10.5	6.8	9.6	9.6	97	95	A	96.5
Y		100	60	60	70	50	60	48	78	28	8.8	8.8	8.9	9.6	82	80	A	90.0
Y		100	60	60	70	50	60	50	80	30	9.5	9	9.4	9.6	80	97	A	94.2
Y		100	60	59	66	50	60	50	78	30	9.1	9.5	9	10	94	95	A	96.1
Y		100	60	60	70	50	60	50	77	30	9.6	9.5	9.2	10	93	94	A	96.3
N		100	60	60	70	49	60	50	80	30	8.8		7.1		40	79	B	71.7
Y		100	60	60	70	50	60	50	80	30	10	9.3	9	9.8	98	93	A	97.3
Y		100	60	60	70	50	60	48	77	30	7.8	8.8	9.1	9.6	72	79	A-	87.5
	weighting factor	7.1	4.3	4.3	5.0	3.6	4.3	3.6	5.7	2.1	5.0	5.0	5.0	5.0	20.0	20.0		100.0

	100	60	60	70	50	60	50	80	30	10	10	10	10	100	100	
ABET Outcome																Course
1	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.1	0.1	0.1	0.1	0.5	0.5	37.4%
2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.5	0.5	38.0%
3										0.05	0.05	0.05	0.05			1.0%
4							0.1		0.1	0.05	0.05	0.05	0.05			1.6%
5										0.3	0.3	0.3	0.3			6.0%
6										0.3	0.3	0.3	0.3			6.0%
7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1			10.0%
(should sum to 1)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	100%

Cutoff Percentages	
65	Unsatisfactory
80	Exemplary

Breakdown of Student Performance by Assignment

	Pset1	Pset2	Pset3	Pset4	Pset5	Pset6	Pset7	Pset8	Pset9	Lab 1	Lab 2	Lab 3&4	Lab 5	Midterm	Final
Unsatisfactory	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Acceptable	0	0	0	0	0	0	0	0	0	1	1	1	0	1	2
Exemplary	9	9	9	9	9	9	9	9	9	8	7	8	8	7	7

Figure 4-1 SEAS ABET Grading spreadsheet (SAGS) for EENG320.

This course-based performance evaluation process is detailed in the following paragraphs. The system takes advantage of the scoring mechanism used within each course and aligns individual assignments, exams, labs and reports with specific Outcomes. The performance of each student in the course measures that course contribution to achieving levels of performance for each relevant Outcome. Because this method is implemented for each course, the data from the individual courses is easily aggregated to provide a comprehensive assessment of the program's overall performance meeting Outcomes.

The SAGS shown in Figure 4-1 contains the following fields that are useful for Outcome assessment.

- *ABET Outcomes* are listed to remind faculty what is being assessed.
- *Performance Rubrics* are filled in by each instructor to indicate how to assess outcomes.
- *"Improvements for next course offering"* is a remark entered by the instructor at the end of the term for modifying the course in its next offering. This is a factor used by the DUS and the Instructor in the EE faculty meeting that discusses Continual Improvement in the Program.
- *Grades* for homework, projects, reports, and tests are entered for each student. Students are not required to declare their major until the beginning of their third year. If this information is

available, ABET students are differentiated from non-ABET students, the latter typically being EE majors in one of the other programs offered by the EE Department and undergraduates from other departments. The comparison of ABET students with non-ABET students is a useful measure for level of outcome attainment. The results typically indicate that ABET students perform at a higher level of outcome attainment than non-ABET students.

- *Distribution of Student Outcomes* indicates what outcomes are assessed in the course and how the outcomes are distributed in each assignment. This initial attempt of applying this worksheet scheme to the EE Program identifies a difficulty with Outcomes assessment: it is noted that assignments typically involve a variety of outcomes, confounding the assessment of a specific outcome from an assignment score. The EE Faculty have discussed this issue and one solution offered is to modify assignments in future course offerings to focus on specific outcomes to allow assignment scores more directly reflect Outcome assessments. As described below, the focus of Outcomes assessment is determined by those particular Outcomes that do not meet the expectations of the EE faculty. These spreadsheets help the EE faculty identify places where improvement can be affected by emphasizing particular Outcomes through the assignments.

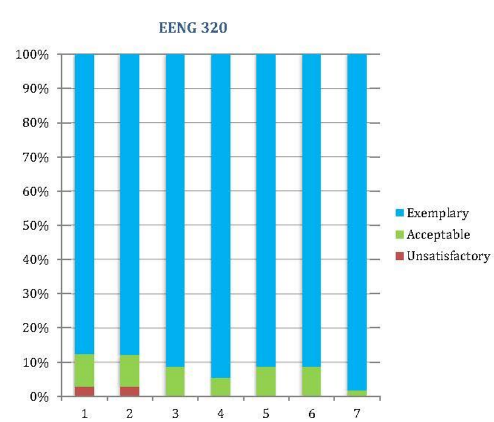
- *Cutoff percentages* are a set of scores specified by the Instructor for the expected level of outcome attainment. For example, the instructor can determine that students receiving a score of less than 60 on any assignment have demonstrated unsatisfactory performance for that assignment. Students receiving a score of 90 or higher are performing at an exemplary level.

- *Breakdown of Student Performance by Assignment* is a summary of student performance for each assignment.

This approach measures the attention each outcome receives within each course and for the program as a whole. The use of coursework such as assignments, projects, reports and exams, whether in whole or in part, as formative assessment tools (i.e., assessment conducted during a course) is standard practice. Using this same collection of student work as a subset of assessment tools is a valid approach as assignments can be structured to target a particular Outcome.

The levels of performance attained for each outcome for each course are displayed as a bar graph. Figure 4-2 shows the results for EENG320.

Results: Course Summary for: EENG 320



Outcome	Unsatisfact	Acceptable	Exemplary	Total
1	3%	9%	87%	100%
2	3%	9%	88%	100%
3	0%	8%	86%	94%
4	0%	5%	91%	96%
5	0%	8%	86%	94%
6	0%	8%	86%	94%
7	0%	2%	97%	99%

Figure 4-2 Outcome Performance for EENG320.

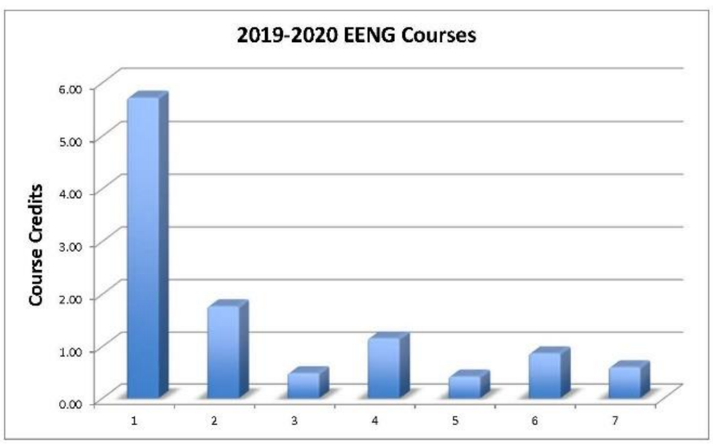
The program-level analysis results from data collected from those courses within the curriculum that are determined as contributing to student outcomes. Figure 4-3 shows the summary for the ABET-EE Program that the SEAS Deans' office generates from the individual ABET-EE course SAGS. This summary provides a bar graph and numerical values indicate how outcomes are distributed over required courses in the program. While previous Table 3-C-1 indicated which outcomes are covered in each course, the table gives the actual contribution of each course towards each outcome. This information helps in determining how to effectively address outcome improvement.

For example, the graph in the summary indicates that outcome 5 is demonstrated by the smallest amount of student work in the program. Noting this, the DUS would bring this to the attention of the EE faculty at the last meeting of the academic year for Faculty who teach courses that claim outcome 5 to consider increasing student work in that outcome. The table lists courses that claim outcome 5 demonstrables as EENG200 (12.0%), 201 (0.6%), 320 (6.0%), 325 (9.3%), and 481 (13.9%). If appropriate for the course, the Instructor of EENG 201 would consider increasing student work for this outcome. The DUS would also suggest to Faculty teaching courses that do not include outcome 5 work, as determined by the table, to consider including an outcome 5 component in future offerings, if appropriate. While Faculty are typically reluctant to make changes to their already *fantastic* courses, they usually do give some thought over the summer break as how to make minor tweaks to better prepare the ABET-EE graduates, thus gently accomplishing continual improvement.

ENGINEERS
BREADTH·DEPTH·PURPOSE

YALE SCHOOL OF ENGINEERING AND APPLIED SCIENCE

ELECTRICAL ENGINEERING ABET OUTCOME REVIEW



	EENG Courses											Total Course Credits
Outcomes	ENAS 130	ENAS 194	EENG 200	EENG 201	EENG 202	EENG 203	EENG 310	EENG 320	EENG 325	EENG 348	EENG 481	
1	100.0%	100.0%	31.3%	69.5%	52.8%	50.0%	30.0%	37.4%	28.3%	58.3%	13.9%	5.72
2	0.0%	0.0%	32.5%	12.4%	47.2%	10.0%	10.0%	38.0%	1.1%	11.7%	13.9%	1.77
3	0.0%	0.0%	0.0%	7.8%	0.0%	5.0%	0.0%	1.0%	10.4%	7.5%	16.7%	0.48
4	0.0%	0.0%	1.3%	0.0%	0.0%	15.0%	60.0%	1.6%	5.6%	18.3%	13.9%	1.16
5	0.0%	0.0%	12.0%	0.6%	0.0%	0.0%	0.0%	6.0%	9.3%	0.0%	13.9%	0.42
6	0.0%	0.0%	12.0%	4.9%	0.0%	10.0%	0.0%	6.0%	38.1%	1.7%	13.9%	0.87
7	0.0%	0.0%	11.0%	5.3%	0.0%	10.0%	0.0%	10.0%	7.1%	2.5%	13.9%	0.60

Figure 4-3 EE Program Summary for AY 2019-2020.

There are several advantages for adopting the SAGS:

1. It is common to all three ABET-accredited programs and thus facilitates discussions involving the respective DUSs and the Dean's office.
2. It gives each EE instructor the opportunity to observe the details of student performance, to reflect on how assignments relate to outcomes, and to review performance criteria for the course. The SAGS version adopted by the ABET-EE program also includes a place to enter notes for improvements in the next course offering. As such, each instructor applies a *miniature version* of the ABET assessment, continual improvement, and level of outcome attainment process to their own course.
3. The SAGS is a concise and consistent record that summarizes outcome assessment in a form that the DUS analyzes for outcome assessment and attainment across the program. The DUS incorporates this analysis as an integral component at the end-of-year EE Faculty meeting where outcome attainment levels and continual improvement of the program are discussed.

I.2 Outcome attainment and continuous improvement.

Although the SAGS was comprehensive, filling it out was an onerous task for some EE faculty. The 200-level courses had large enrollments that contained a majority of students that eventually did not become ABET-EE majors. The 300-level courses typically contain a majority of ABET-EE students, but this small number received individual attention from the Instructors, who felt that they mentor students to achieve higher than adequate levels of outcome attainment.

An attempt was made to provide a faculty-friendlier approach to outcome attainment as well as continuous improvement in addition to the SEAS spreadsheet. The result was a shorter form that could be utilized biannually while producing data that complements those from the SEAS spreadsheet. The attempted solution was the Short ABET form shown in Figure 4-5.

The short ABET form was a PDF-fillable form that is completed at the end of the semester, based on each student's performance, which is well-known to the Instructor. In the term a course was scheduled to use the SAGS, the Short ABET form was not necessary.

The small number of ABET majors allow Instructors to make a general assessment of student achievements: Strong and weak students become apparent early in the course. Being aware of the ABET outcomes, Faculty mentor students to achieve an adequate level that is expected of an ABET-EE major. Students who do not meet expectations are noted and their number is entered on the form. Such data is helpful in Faculty discussions regarding outcome attainment and improvement. In the short ABET form shown in Fig. 4-5, the Instructor assessed all four ABET-EE students, five of the seven outcomes were achieved by all student, outcomes 3 and 7 were not achieved by two students and one student, respectively. The narrative entered by the Instructor provides a perspective on the success of previous course improvements as well as the improvement implemented for the next course, motivated by the outcomes that were not achieved by all ABET-EE students.

ABET Course Assessment (Rev. 051418)

EENG: 320

Instructor: Reed

Academic year taught: AY17-18 | Fall: X | Spring:

Total enrollment: 9 | ABET enrollment: 4

Grade distribution:					
	A: 6	A-: 2	B+:	B: 1	B-:
	C+:	C:	C-:	D:	F:

Outcome achievement (# of ABET students demonstrating outcome competence)					
	1) 4	2) 4	3) 2	4) 4	5) 4
	6) 4	7) 3			

Improvement suggested in previous year incorporated into this offering	Refocusing laboratories to include more material while keeping the number of labs the same; change lab report format.
Assessment of previous year's improvement	Reduced the number of laboratories due to student complaints of workload. Students reacted very positively, thought workload was appropriate.
Proposed improvement(s) for next course offering	Consider new textbook or other supplemtary material for the textbook.
Motivation for specified improvements	Some negative student feedback on homework problem sets and worked problems.

Figure 4-5 Short ABET form for EENG320.

Table 4-2 gives the criteria for assessing each Outcome applied to each student for Faculty guidance.

In preparing this report, it has become evident that the current version of the short ABET form can be improved, as described below, to specify the course improvements explicitly towards improving outcome attainment.

Table 4-2: Criteria for Outcome Assessment using the Short ABET Form

Outcome	1	2	3	4	5
1	Applied algebra with little calculus, did not understand what needs to be done	Incorrectly applied calculus, did the first thing that comes to mind	Applied standard equations correctly, considered several alternatives	Applied advanced mathematics, systematic approach to find good solution	Used math for optimization, found the best solution
2	Did not know how to design system to complete a task	Needed help throughout the design process to understand the standards and constraints	Designed a simple system that meets the standards and constraints	Designed a complex system that meets the standards and constraints	Incorporated the standards and constraints to design an optimized system
3	Gave incoherent explanation	Had some incomplete thoughts	Had good ideas and reasonable logic	Gave good arguments but not suited to audience	Made convincing and clear arguments
4	Had no idea why project is important, unaware of anything that is not related to engineering	Did not understand most issues and needed help to design a system that takes any one of them into account, had a passion for engineering but no awareness for other social issues	Avoided apparent conflicts and ethical issues, understood many of the issues and designed a system that took them into account	Attempted to understand and apply good practices, understood most the issues and designed a system that took them into account	Had a thorough understanding of safety and ethical considerations and references, understood most the issues and incorporated them into the system design
5	Was uncooperative and antisocial	Was social but did not fully contribute	Did fair share of work	Added to group learning experience	Led group while being a team player
6	Was incapable of designing meaningful experiment	Needed help to set up an experiment and acquire data	Designed experiment and has some understanding of data	Skilled in selected fields for experiments and data analysis	Performed novel experiments that produced data that confirmed a hypothesis
7	Could not proceed without constant handholding	Used only information provided	Found alternatives on the Web	Learned how to adapt systems found on the Web	Used newest devices and current information on the Web

I.3 Assessment of capstone project

The ABET-EE Program capstone design project incorporates topics learned in the prerequisite courses and teaches a design process that develops specifications, schedule, cost analysis, accepted standards and constraints, and conforms to safety and ethical norms. The EENG481 capstone projects are designed to have all students demonstrate attainment in all ABET outcomes.

Preparations for EENG481, which occurs in the spring term, start in the middle of the fall term, when the Instructor schedules a meeting of the ABET–EE seniors to discuss project ideas. By the end of the Fall term, the project theme for the team has been finalized by consensus of the ABET-EE students and Instructor, and student-specific projects have been assigned. Parts for implementing the projects are suggested by each student in consultation with the Instructor and the EE lab manager (Kevin Ryan) and ordered prior to the winter break for arrival before the start of the spring term. Being aware of their projects, students are encouraged to prepare by investigating potential implementations on the Web. This presentation allows for a lively discussion of alternatives at the first team meeting during the first week of the spring term.

Table 4-3 summaries the capstone project details.

Table 4-3: Capstone Project Summary

Class year	Team Project	Number of EE ABET Program seniors	Term Taught	Instructor
2017	Autonomous robot (Instructor suggested)	7	Spring ‘17	R. Kuc
2018	Autonomous mobile robot sensing and control (Instructor suggested)	8	Spring ‘18	R. Kuc
2019	Personal wireless audio communication channel (student selected)	4	Spring ‘19	R. Kuc
2020	Mobile robot control using ML (student selected)	6	Spring ‘20 (Covid 19 forced online course for half term)	R. Kuc

The instructor of the capstone project integrates the outcomes learned in prerequisite courses into the design of a system along with additional topics required for setting the specifications, forming a schedule using a Gantt chart that includes component acquisition, interfacing, and testing. These issues, along with safety and ethical considerations, are covered in the texts by Ford & Coulston *Design for Electrical and Computer Engineers* and by H.F. Hoffman’s *The Engineering Capstone Course: Fundamentals for Students and Instructors*.

The instructor also provides a template for a successful report that also contains a section in which the student describes their demonstrable ABET-EE Program outcomes. This makes graduates keenly aware of the meaning of an ABET-EE degree. After the students have handed in their report, the instructor assesses each Outcome in the report, in the presentation, and in his interactions with the student during the term.

Table 4-4 gives the assessment data by the EENG481 Instructor for each Outcome for each ABET-EE senior for the past 4 years using the criteria previously given in Table 4-2. The Instructor is familiar with the ABET outcomes and during individual and team meetings mentors students toward achieving the expected levels for each outcome during the capstone design process. The Instructor urges students not to be afraid of mistakes, advising them "it is better to make a mistake at Yale and learn from it, rather than making the mistake in your career." During the design process the achievement of each outcome for each student is probed. For example, each outcome is considered below by its number.

1. Each student is given a specific task that incorporates applying principles of engineering, science, and mathematics. Students who are facile with these principles have attained this outcome, while those who have difficulty applying theory to practice are given explanations. At the end of the course the Instructor can assess the student's attainment of the outcome.

2. An engineering design produces a solution to the specific task. Usually, a design that just works in not sufficient. A working system is typically implemented by mid-term. It the second half, the student thinks about design improvements and their implications. The course requires that the design optimizes a criterion: It is either most theoretically accurate, consumes the least energy, cheapest or fastest, for example.

3. The design of the presentation and poster explains the most important accomplishments of the project in a clear, concise, and correct manner.

4. The liberal arts component of the ABET-EE curriculum gives students the basis for understanding their ethical responsibilities. The format of the design course presents engineering situations that teach the professional responsibilities, such as crediting design ideas found on the Web and acknowledging help by the laboratory staff.

5. The project is designed so that each task becomes a necessary part of the final working system. In addition to working on their specific project, each student is a member of a team that makes decisions on scheduling and reassessing goals when new components are found to improve performance, or catastrophic failures occur. How individuals cooperate is this setting determines the level of attainment.

6. Each task requires an understanding of the current practices to achieve similar tasks and to determine the novelty of the task in context of the system being implemented. With the time constraint imposed by the semester, each student must make compromises to develop a working system.

7. Yale generously supports EENG481 projects with budgets of up to $3,000 for equipment, and occasionally even more. This allows students to search for the newest devices (sensors, cameras, microcontrollers, robot kits, etc) for developing a system. (The Instructor urges that the final product have a "wow" factor for enticing applicants to Yale Engineering and First-years to consider majoring in engineering.) Most Yale seniors are very adept at using the Internet to find the newest devices and techniques.

Table 4-4: Outcome Attainment from Capstone Project

Class year	Student	ABET Outcome						
		1	2	3	4	5	6	7
2017	1	5	5	5	5	5	5	5
	2	4	4	4	5	4	4	3
	3	5	5	4	4	4	4	5
	4	4	4	4	4	3	4	4
	5	5	5	5	5	5	5	5
	6	5	3	4	5	5	5	5
	7	5	3	4	3	4	4	4
2018	1	5	5	5	5	5	5	5
	2	4	4	4	4	3	4	3
	3	4	4	4	4	4	4	4
	4	5	4	5	5	5	4	4
	5	5	5	5	5	5	5	5
	6	4	4	4	4	4	4	4
	7	5	5	5	5	5	5	5
	8	5	5	5	5	5	5	5
2019	1	5	4	5	5	5	5	5
	2	5	5	5	5	5	5	5
	3	4	4	5	5	5	5	5
	4	5	5	5	5	5	5	5
2020	1	5	5	5	5	5	5	5
	2	4	3	4	4	4	4	3
	3	5	5	4	5	4	5	5
	4	5	5	4	5	4	5	5
	5	5	5	5	5	5	5	4
	6	5	5	5	5	5	5	5

Table 4-5 summarizes the data by giving the maximum and minimum attainment values for each Outcome for each student in each year during the past four years based upon the capstone project and the report.

Table 4-5: Max/Min Values of Program Outcome Attainment from Capstone Project

Class year	Maximum Values for each Program Outcome						
	1	2	3	4	5	6	7
2017	5	5	5	5	5	5	5
2018	5	5	5	5	5	5	5
2019	5	5	5	5	5	5	5
2020	5	5	5	5	5	5	5

Class year	Minimum Values for each Program Outcome						
	1	2	3	4	5	6	7
2017	4	3	4	3	3	4	3
2018	4	4	4	4	3	4	3
2019	4	4	5	5	5	5	5
2020	4	3	4	4	4	4	3

The analysis of these data shows the following:

- All outcomes during these years were assessed to be at an acceptable level ($\geq$3), although most outcomes were assessed to be achieved at a higher level. This gratifying result is one indication used by the EE faculty to determine that the ABET-EE Program has achieved its goal regarding the level of outcome attainment.

- The exemplary level (5) for each outcome was achieved by at least one student during the past four years. Increasing the minimum level from the acceptable level for all students has become the current goal of the EE faculty for the ABET-EE program.

II. Qualitative Direct Outcome Assessment Process.

One qualitative direct outcome assessment process was employed as given in Table 4-6.

Table 4-6: Qualitative Outcome Assessments

Process	Frequency	Assessor	Expected level of attainment	Results	Documentation
Assessment of capstone project presentations	yearly	Instructor and EE Faculty	At least acceptable for all students	Typically acceptable	EE faculty meeting minutes

EE Program students are required to give a presentation of their contribution to the ABET Team project. In addition to an oral presentation to students, friends, and Faculty, each senior prepares a poster for a session immediately after the presentations that gives the Faculty an opportunity to ask probing questions. In general, our ABET-EE graduates give polished presentations and can provide in-depth answers to most questions, especially gratifying to Faculty who taught the subject. By the senior year, the Faculty know each student individually, along with their strengths and weaknesses. On this basis of this familiarity, the Faculty can assess each outcome and its level of attainment. The discussion at the last faculty meeting of the academic year is typically satisfying, especially when the DUS indicates that, with rare exceptions, each graduate is embarking on their chosen career.

A method to convert this qualitative assessment process in the next academic year into a process that gives a quantitative assessment is described below.

III. Indirect Outcome Assessment Processes.

Two indirect outcome assessment processes are employed and are listed in Table 4-7 and described below.

Table 4-7: Indirect Outcome Assessments

Process	Frequency	Assessor	Expected level of attainment	Results	Documentation
Student course schedule meetings	Each semester	DUS	At least acceptable ($\geq$3) for all students and all outcomes	Typically achieved	DUS notes
Feedback from recent graduates	During student visits and requests for letters	Faculty	Successful in chosen PEO	23 ABET-EE graduates since 2010 were in successful careers	Notes taken at Graduate/Faculty meetings and emails

1. Student course schedule meetings – All EE majors must have their course schedules signed by the DUS during a scheduled meeting at the start of each term. The EE Program students are given copies of the seven ABET outcomes. Prior to these meetings the DUS reviews the course SAGS and short ABET forms to determine the performance criteria and suggestions for course improvements. The DUS has a discussion about the previous term courses – for suggestions to instructors for continual improvement – and about the students concerns regarding level of outcomes attainment.

   This process gives the DUS a good assessment of the state of the ABET-EE Program from the student's point of view, especially regarding problem areas for the attainment level of particular outcomes. If the DUS determines a problem exists, they set an agenda item at the next faculty meeting for the EE faculty to discuss and resolve the deficiency.

2. Feedback from recent graduates – Twenty-three ABET-EE graduates from the last 10 years provided feedback through their visits to campus as recruiters, for reunions or through emails from graduates who requested reference letters. These recent graduates are queried regarding the impact of the ABET-EE program on achieving their PEOs. These twenty-three graduates represent approximately half of the ABET-EE graduates since 2010. As expected, these graduates were employed in the following careers that align with the four PEOs set by the EE faculty for the ABET-EE program.
    a. Ten were working for engineering companies, most in managerial positions (Microsoft, IBM, Boeing, Cummins, and National Labs).
    b. Six were currently in graduate programs at top-tier universities, including MIT, Stanford, CMU, UC Berkeley, Michigan, and ETH, or had completed their MS or PhD degrees.
    c. Three were in management of start-up companies.
    d. Four completed Business, Law or Medical Schools.

    Without exception, they all commented positively on how the rigor, intellectual depth and Faculty support of Yale's ABET-EE program prepared them to succeed in their chosen, and competitive, careers. Especially noted was that the ABET-EE program taught them problem solving skills, to consider solutions from various technical and social aspects and exceptional communication skills and made them better prepared than engineering graduates from technical universities. The Yale ABET-EE program takes such responses as an affirmative qualitative assessment of outcome attainment.

<u>Process for determining level of attainment of Outcomes for the ABET-EE Program.</u>

The DUS collects the outcome assessment data described above and indications regarding actions for continuous improvement. The focus of discussions at faculty meetings, which almost always contain the agenda item "ABET", addresses issues related to Outcomes assessment and level of attainment. Outcomes that do not meet the expectations of the EE Faculty receive special attention.

The EE Chair sets an ABET agenda item on the last EE Faculty meeting of the academic year to notify the EE Faculty that ABET Outcome Attainment and Curriculum Improvement will be discussed. The EE Faculty who teach ABET-required courses review their course summary assessments and the EE Faculty present at the recent EENG481 capstone project presentations recall their notes. At this meeting, EE faculty have knowledge of the outcome assessment in their own course and the assessment of the senior project presentation. The DUS also describes the career plans of the ABET graduates. These data prepare the EE Faculty to have an informed and meaningful assessment of outcomes across the program, of the level of outcome attainment, and of possible improvements in the curriculum. At this meeting the EE Faculty also nominate the two award winners to the SEAS Dean. One award, the Lanphire Prize, goes to the senior achieving highest GPA and the other, the Tuteur Prize, to the senior accomplishing the best research project. These prizes typically are awarded to ABET-EE program graduates.

B. Continuous Improvement

The process to continuously improve the ABET-EE outcomes is based on quantitative measures of outcome assessment and attainment from the SAGS and the short ABET form.

An example of a four-step process that uses these forms is illustrated for the EENG320 course.

1. *Assessment:* The Short ABET form shows that two students were assessed not to have achieved outcome 3 and one student not to have achieved outcome 7.
2. *Analysis:* The SAGS shows that outcomes 3 and 7 are assessed in Labs 1 through 5.
3. *Improvement:* Using this information the EENG320 was improved adjusting the labs to allow more opportunity for students to explain their designs (outcome 3) and by introducing supplemental information (outcome 7).
4. *Verification:* This process for EENG 320 was successful: While the Short ABET form was for the 2017 offering of the course, the SAGS assessed the current Fall 2019 offering. Its outcome performance summary in Fig. 4.2 shows that all students attained outcomes 3 and 7, indicating the improvement in the labs was successful. However, the summary also shows that outcomes 1 and 2 were not achieved by one student. Upon closer examination of the SAGS, the student did not complete labs 2 and 5, and was not an ABET-EE student by the end of the course.

   This process illustrates a feature that is unique to Yale SEAS. Even though all Yale undergraduates are bright, few have the desire to put in the effort to complete an ABET-accredited program. Yale EE gives students three additional less-intensive, non-ABET degree options. The ABET-EE program in thus improved by forming a dedicated small group of students that complete the ABET-EE program. Of course, a more desirable approach is to tout the high ABET-EE standards to entice more Yale students to meet these high standards. This second approach is done during the meetings with First-years searching for degree programs and during DUS meetings with students deciding on course schedules.

The EENG 481 capstone course acts as an additional verification of outcomes achievement for the ABET-EE program. This is afforded by the small number of ABET-EE students in the course, who the Instructor mentors individually. Marginal outcome attainment, such as the 3's in Table 4.6 indicate that additional effort should be considered in those outcomes in ABET-EE courses that teach that outcome. The results of this analysis are presented at an EE faculty meeting for those Faculty teaching course that list those outcomes to consider improving their courses.

Of course, with such small number of ABET-EE students, one could argue that it is the variation in the ability of the students themselves that cause the variation in the outcome assessment data. While that may be true, the process for continual improvement is still important for the Yale ABET-EE program to continue to produce quality engineers.

<u>Improvements in the ABET-EE Program from Outcome assessment</u>

The ABET-EE Program's focus on attaining student outcomes at an acceptable level and preparing students to achieve PEOs has produced a number of EE Program improvements over the period the accreditation cycle of 2015-2020. In general, these improvements can be classified as improvements that have resulted from the Outcomes assessment processes and as operational improvements. These improvements are described in the following paragraphs.

Since the 2014 ABET Self-Study, the Outcome assessment process resulted in the following improvements in the ABET-EE Program.

<u>EENG 320 *Introduction to semiconductor devices: Outcomes (3) and (7) improved.*</u>

As described above in more detail, the F19 SAGs indicated that the F18 offering should be improved in the following two ways because the short ABET form showed not all ABET students attained sufficient outcomes (3) and (7):

1. Labs were restructured to better align with material.
2. Revisions of BJT and heterojunction material for clarity.

The F19 offering modified the lab component, and the SAGS shows improvement by the attainment of outcomes (3) and (7) by all ABET-EE students.

EENG348 Digital Systems: Outcome (3) component added.

In 2017, there was only one EE junior professor in the area Computer Engineering, and that professor was teaching the popular ABET-EE required course EENG201. A professor from the Systems area volunteered to teach the ABET-EE required course EENG348. That offering of the course had 15 students, mostly EE majors, and taught microcontroller control of sensors that required some analog circuit design. This non-traditional computer engineering course limited outcome attainment for students who wanted to concentrate in that area. Specifically, there was no ABET outcome (3) component.

The EE faculty recognized the need to bolster the computer-engineering faculty and hired a senior professor who taught EENG348 in 2018 with topics that were traditional in that area. The enrollment more than doubled to 37 students who implemented digital systems that were of individual interest using a variety of digital components, including FPGAs, MCUs and smartphones. These students demonstrated their designs during an open-house poster presentation to Faculty and students, including freshmen interested in EE. These presentations added outcome (3) to EENG348, which the Faculty assessed as contributing to its attainment. Since 2018, EENG348 has been popular with the students and has had large enrollments.

EENG 481 *ABET Capstone Project: Improving level of outcome attainment.*

From Table 4-6, the attainment of outcomes (5) and (7) in the 2017 and 2018 offerings of EE481 shows attainments with scores equal to the satisfactory threshold (=3). The analysis of minimum values of outcome attainments showed this to be a trend that should be corrected.

Outcome (5) was assessed with a score of 3 because the course structure allowed students to work on separate projects that, although successful, did not interface with the mobile robot in sufficient time to allow optimizing the system.

Outcome (7) was assessed with a score of 3 because students did not seek help in their projects when needed in the group meeting – it was too easy to hide. As a result, each student proceeded trying to improve a flawed design that could have been replaced with a more conventional approach.

The 2019 offering of EENG481 recognized these shortcomings and resolved them by replacing the group meetings with individual student meetings at the beginning of the course. Group meetings were held when the project was closer to completion.

This improvement allowed the minimum attainment levels in EENG348 to increase from 3 to 4.

EENG 481 *ABET Capstone Project: Incorporating Data Science and Machine Learning to strengthen outcome (7).*

The EE faculty recognizes the society-changing impact of Data Science and Machine Learning. Since the 2014 ABET review, the EE department has hired 1 senior and 2 junior faculty with software and hardware research interests in these areas. These faculty introduced the following new courses to the curriculum for the systems track:

1. EENG431 Foundations of Data Science
2. EENG451 Wireless Technologies and the IoT
3. EENG452 Internet Engineering
4. EENG455 Network Algorithms and Stochastic Optimization

Even though these courses are electives and not required, they are being taken by ABET-EE students. EENG481 has encouraged students taking these electives to apply this knowledge to their senior project to strengthen attainment of outcome (7) by applying then additional knowledge. This has already occurred with the 2020 version of EENG481 that that had one student investigate Reinforcement Learning for mobile robot navigation.

Future improvements to enhance Outcome assessment

Generating the ABET self-assessment report provides an opportunity to see the big picture and devise methods to enhance outcome assessment and improve outcome attainment going forward. These methods are described in this section.

Improving the Short ABET form

The current Short ABET form gives quantitative information about individual outcome attainment. In the course improvement dialogue, a question will be added to ask how the improvement relates to improving the attainment of an ABET outcome. This small addition should help focus attention of course topic presentations onto outcome attainment.

Improving the qualitative presentation assessment into a quantitative assessment

The reduction of ABET's previous eleven a-k outcomes into the current seven outcomes, along with the small number of ABET-EE graduates, offers the following opportunity to enhance outcomes assessment from the qualitative assessment of outcomes attainment from the project presentations described above to one that is quantitative.

Not counting the EENG481 capstone project, there are eight courses required for the ABET-EE program. Starting next year, the instructor of each required course will be assigned one of the seven outcomes randomly and be given an outcome-specific sheet, (1) through (7), containing the names of all the ABET-EE seniors. During the poster presentation, the instructors will query each ABET-EE student to assess their attainment of their assigned outcome and enter a score (1-5) on the sheet, thus obtaining a quantitative measure of each outcome attainment for each ABET-EE senior.

This process will be implemented in the next academic year and become an annual assessment. This process will also benefit the EE faculty by acquainting them with the various means the students attain these outcomes.

Operational improvements

A number of Program improvements have been made over the 2015 - 2020 period that have increased the profile of Yale Engineering, and the EE Program, on and beyond the campus. Included in this increased profile are more opportunities for engineering students and an increased appreciation for engineering at Yale. Though difficult to characterize and quantify, it is generally stated that the School of Engineering is on an upward trajectory as reflected in an increased Faculty size, expanded infrastructure (notably the creation of the Greenberg Engineering Teaching Concourse to address engineering teaching lab needs) and a rise in undergraduate (and graduate) applications. These facts have combined with a growing interest by industry in the Program's graduates.

Such results are made possible by a number of factors. Financially, the improvements have been accelerated by investments by Yale in the School of Engineering and an increased level of philanthropy devoted to Yale Engineering. As an example of a systematic improvement, the Program's association with Yale's Office of Undergraduate Admissions has strengthened over this period with an increased number of Program faculty being involved in traditional and new programs sponsored by that office to recruit engineering-bound applicants. At the other end of the student development timeline, a number of School-wide initiatives have better prepared graduates for the next steps in their careers. These include initiating engineering industry nights within the Center for Engineering Innovation and Design (coordinated by Yale's Office of Career Strategy) and fostering connections between current students and Program alumni.

The student chapter of the IEEE (Y-IEEE) has become more active. In cooperation with the CT Chapter of the IEEE, the Y-IEEE has hosted a yearly seminar by an EE Faculty describing their research projects, followed by tours of SEAS facilities. They have also proposed a research project entitled *The Yale Space Station.* In 2019 they organized a team of Yale undergraduates that designed a radio transmission system to bounce a signal off the moon to measure the speed of light, followed by a second phase that would communicate with the International Space Station. The project is *Yale-scale* in its quality and impact, especially having the *wow-factor* that is important for attracting applicants to Yale SEAS and majors to the ABET-EE program. The Yale Science and Engineering Alumni (YSEA) provided funds for a radio antenna and the associated transmitter and receiver electronics.

The engineering community at Yale has been strengthened over this period of time with the development of programs such as the coordinated welcome and advising sessions held during the first days of the new students' arrival on campus each fall. An increased in the number and accomplishments of Yale Engineering clubs and associations has also occurred, thereby providing engineering students with opportunities to extend their professional interests using extracurricular activities. These developments have been accompanied by an increased attention to traditional and electronic publications. These include the development of a School-wide magazine (that often covers undergraduate topics), an Engineering View Book (for admissions recruiting and first year advising) and an active School web site (that details many activities as news items on the site and in social media).

The creation and utility of the CEID has been a significant improvement that has advanced the culture for engineering at Yale. Specific examples of its impact have been documented in the annual magazine Yale Engineering and online in the Yale SEAS News.

Since the CEID is open to the entire Yale community that is interested in developing innovation, creativity and manufacturing skills, EE students have the opportunity to benefit from its arrival on campus, primarily by participating in student-originated design organizations (such as the Autonomous Vehicle project and the Mars Rover project) that are based in the CEID.

The investments made to infrastructure within the Electrical Engineering program since 2014 have been significant. As detailed in Chapter 7 of this Self Study, as well as in press reports during this period (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 (GETC) has 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 for the new labs is the donation of all new electronics equipment within the facility by a

Yale EE alum, thus signaling one example of the strong affiliation of our alums and the program. Of note with respect to the EE program and the new labs is the fact that the far majority of the new 10,000 square foot facility is aligned with and used for program needs.

While the GETC facility includes six independent dry labs and two wet-labs, three of these are fully outfitted for program delivery and a fourth lab is configured as needed to host EE labs (and 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 lab courses. By design, prospective students, visitors, and other members of the Yale community have an unimpeded ability to witness the actions and activities of the program's students and faculty as they work in a state-of-the-art facility to learn basic and advance fundamentals and to design new electrical and electronic products. The new facilities are highly valued by the program's students as they provide spacious room, modern design, and advanced equipment to engage in product courses and design projects. This infrastructure investment has also been accompanied by an investment in related electrical engineering technology as detailed in Chapter 7 of this report and includes the addition of a state-of-the-art circuit board plotter for in-house rapid PCB prototyping, a semi-automatic system for assembling surface pneumatically place and mount components on circuit board, and the addition of ventilation stations to allow 24 students to simultaneously and safety solder components within a single lab.

This investment by Yale University into the undergraduate EE program 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 GETC has become 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 lab outfitted spaces with new technology to conduct remote instruction and coordinated activities to share education innovations related to on-line 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 (GETC, CEID, 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.

Similar to the program improvements accelerated by the investment in infrastructure, the program continues to benefit by the dedication to and addition of hands-on design activities throughout the curriculum by taking advantage of the resources available in the GETC and the CEID. For example, students now have the ability to design and fabricate their own printed circuits boards, with this ability manifested in individual student projects (such as the design/fabrication of a "personal Ardunio" as well as program-invented Field-Programmable Gate Arrays which are then provided to each student for use in an Embedded Systems course). The program's Digital Systems course provides additional insights into the proliferation of hands-on design activities that strengthen the program with that course's focus on the integration of electronics and coding to produce demonstration projects based on course fundamentals. The course designs are presented with the artifacts from other design courses, including capstone design, in a program-wide demonstration-day celebratory event that brings together students and faculty (including those from related disciplines) to celebrate student success. A further example of the use of resources to build community has resulted from student-led projects that have created LED-light boards, a copy of the original Macintosh computer, and HAM radio stations, with these products distributed around the engineering campus to showcase and celebrate the program's contributions to society to other students and faculty, all a part of strengthening Yale Electrical Engineering community. These elements of showcasing student success and building community demonstrate one aspect of the program's continuous improvement process.

C. Additional Information

The following links provide additional information on the Yale Method of Student Outcome assessment. These links have been used to inform the Yale Engineering Faculty about this process and guide them in preparing the course-based performance evaluation spreadsheets.

http://seas.yale.edu/sites/default/files/ABET%20Yale%20Method%20White%20Paper_Student%20Outcomes-8-5-13.pdf

http://seas.yale.edu/sites/default/files/5-DUS-Guide-for-Using-Program-Assessment-for-Student-Outcomes-Spreadsheet.pdf

CRITERION 5. CURRICULUM

A. Program Curriculum

The EE Program curriculum is published in the *Yale College Programs of Studies (YCPS)*. The edition issued during the student's first year represents that student's requirements for graduation, so that any changes introduced during the students following three years are optional for that student. The curriculum lists the prerequisites, the required courses and electives required to earn a degree. Sample programs spanning a student's four years provide guidelines for EE students.

Table 5-1 describes the plan of study for students in this program including information on course offerings in the form of a recommended schedule by year and term along with average section enrollments for all courses in the program over the two years immediately preceding the visit. This schedule is typical for a student who has no college-level mathematics preparation in high school. Such students take the first two semesters of calculus (MATH112 and MATH115) in their first year. Students who have Advanced Placement credits in calculus can start with the third semester of calculus (ENAS151 or MATH120) and have more flexibility in their schedules.

Figure 5-1 illustrates a flow chart that shows the prerequisite courses that lead to each required course. Several options are available, depending on the math and science preparation a particular student has. For example, a student having very little math and science course work in high school is advised to start with MATH 112 and PHYS 150. Students with stronger preparations are advised to start with MATH 115 and PHYS 180. Students with exceptionally strong preparations are advised to start with MATH 120 or ENAS 151 and PHYS 201. Yale's start-of-semester *shopping period* allows students to visit course meetings for the first week to determine the intensity is suitable. An additional feature of the Yale program that helps student select the right course is that all the physics courses meet at the same time, and math courses meet in small sections at a variety of times, thus simplifying any schedule change that may be necessary.

The EE Program does offer a cooperative education to satisfy curricular requirements.

The culminating design experience in the EE Program is EENG481 *ABET capstone project*. The capstone project incorporates the knowledge and skills acquired in earlier course work into the design of an engineering system that is open-ended and in a multi-disciplinary setting. Trying novel approaches, making mistakes, experimenting, and evaluating alternative solutions are encouraged to enhance the student's learning experience. Engineering standards take the form of device specifications or data sheets obtained from the manufacturer, usually through on-line Web pages. As background, previously attempted solutions are found in the published literature by doing Google searches and a library search of other textbooks and manuals.

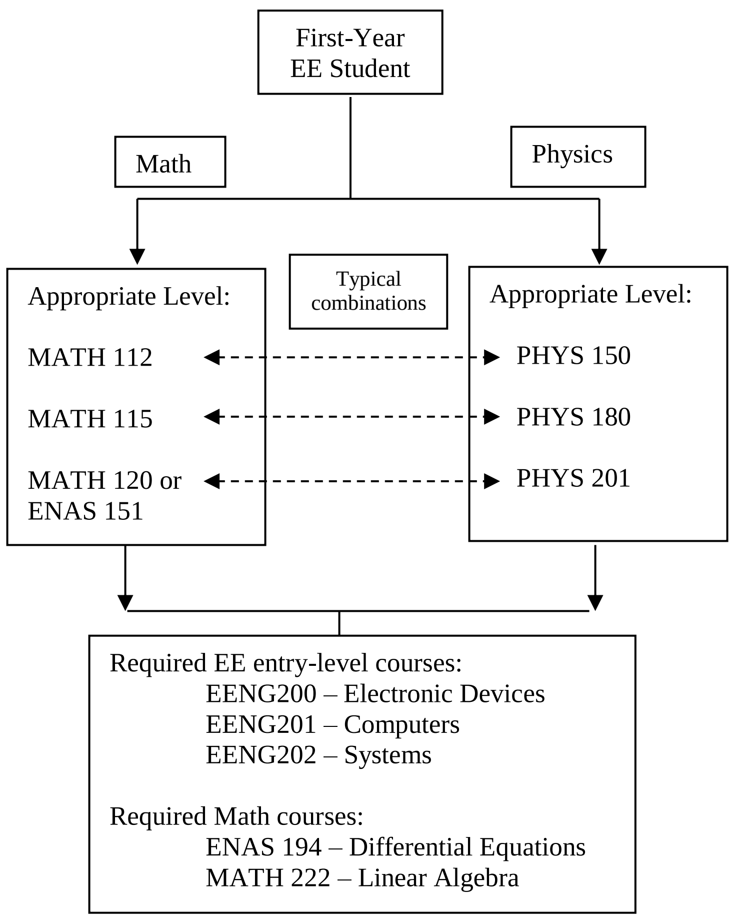
About one-quarter of our ABET-EE program students intend to pursue graduate study. For them the elective EENG471a/472b project course provides research experience in one of our faculty research laboratories. It is not unusual for these students to publish their work in peer-reviewed journals and to be accepted at their first-choice graduate programs.

The general education portion of the curriculum consists of nine courses, which combine with the other courses to fulfill the Yale College requirement of 36 courses. These nine courses are chosen from a wide variety of courses offered at Yale, with the majority of these nine courses also fulfilling distributional requirements established by Yale College in areas that include the humanities and arts, social sciences, foreign language and writing. Yale College also has a distributional requirement in the sciences and quantitative reasoning. The required EE Program courses fulfill the distribution requirements in these areas.

The curriculum leads to a strong foundation in Electrical Engineering, the underlying basic sciences, and in general education. It also allows sufficient flexibility to develop individual student interests. The Program strongly believes that such a foundation prepares students well for their future paths, in particular, professional practice or graduate / professional school. Hence, the curriculum is in strong support of EE-PEOs 1, 2, and 3.

Finally, the foundational science/engineering knowledge, the general education knowledge, and (more broadly) the Yale Residential College experience also enable students to develop as professionals in non-traditional Electrical Engineering fields, and thus support EE-PEO 4.

Figure 5-1 Flow chart of prerequisites leading to required courses.



Regarding the EE Program Program's ability to meet the requirements in terms of hours and depth of study in Math and Basic Sciences, Engineering Topics, and General Education, Table 5.1 illustrates the courses that meet the required criteria. The math portion of the curriculum consists of mathematics through differential equations, linear algebra, and statistics. The science portion includes two semesters of physics and electromagnetism (APHS 322) – for a total of nine math and science courses. It is noted that many students come to Yale having sufficient math preparation so as to enter the curriculum at a higher math course. These substitutions are all reviewed by the DUS during their first year, and any decisions are noted on the Course of Study Form.

EE Engineering Design Curriculum.

Regarding the role of design in the curriculum, engineering design is an integral part of the EE Program. EE students have significant opportunities to pursue engineering design through the curriculum (as indicated by (√) in Table 5-1), the CEID, and extracurricular activities that are sponsored by SEAS. The components of the curriculum are detailed in the following paragraphs.

EENG201 *Introduction to Computer Engineering*: Students typically take this course in their first year. The course introduces the student to the design process using software that program a field-programmable gate array (FPGA), a standard digital component in the EE field. Students then design, construct, and program of a simple processor.

EENG203 *Circuits and Systems Design*: Students design filters, circuits and simple systems using analog components to verify the analytic methods. The course requires understanding of basic circuit theory, detailed analysis of electronic circuits, design and fabrication of a circuit board.

EENG348 *Digital Systems:* Students learn to implement systems incorporating digital devices, such as microcontrollers (MCUs) and FPGAs with a current integrated development environment (IDE). These systems communicate data between the MCU and MATLAB (for its graphic capabilities) running on a laptop or with smartphones for their communication capabilities. The students use these tools to implement systems of their own choosing. At the end of the course, each student demonstrates his system in a poster session attended by students and Faculty.

EENG481 *Advanced ABET Projects*: This culminating design experience in the EE Program is described below.

Center for Engineering Innovation and Design (CEID).

There are a number of ways in which the CEID provides engineering design opportunities to EE students. 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 PhD-level (Physics and Biomedical Engineering) design guides, and two full-time BS-level design fellows as well as undergraduate aides to field questions about the equipment and design process.

Second, the CEID has introduced a summer fellowship program to help students pursue their engineering design ideas. Doing this summer fellowship, teams of students are supported to pursue their own design inquiries. In 2019, the CEID supported three design teams, and in 2020 it is supporting six design teams. In 2020, the six teams of CEID fellows span museum exhibits, automated foord preparation, airflow 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,” our 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 to solve local design challenges to improve the community; and “Engineers without Borders” which has a decade-long project that supplies 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 promoting a culture for engineering at Yale.

The broad education component.

The general education portion of the curriculum consists of nine courses that combine with the other courses to fulfill the Yale College requirement of 36 courses. These nine courses are chosen from a wide variety of courses offered at Yale, with the majority of these courses also fulfilling distributional requirements established by Yale College in areas that include the humanities and arts, social sciences, foreign language and writing. Yale College also has a distributional requirement in the sciences and quantitative reasoning. The ABET- EE Program courses fulfill the distribution requirements in these areas.

Yale undergraduates can *shop* courses for ten days at the beginning of each term before actually registering for them. The meeting with the DUS occurs during this 10-day period. Depending on the PEO selected by the student, the DUS suggests courses that help students to prepare for their career aspirations.

The curriculum leads to a strong foundation in Electrical Engineering, the underlying basic sciences, and in general education. It also allows sufficient flexibility to develop individual student interests. The ABET-EE Program strongly believes that such a foundation prepares students well for their future paths, in particular, professional practice or graduate/professional school.

Major design experience.

The capstone project, EENG481 *Advanced ABET Projects,* is the culminating design experience in the EE Program. The Instructor started his EE career at Bell Telephone Laboratory as a research and development engineer. This experience adds another dimension into the course by including the practical aspects in the design process, such as the importance of developing a realistic schedule that terminates in a working system by the end of the term, making sure that viable alternatives are available to prevent *show-stopping* developments, and forming a setting where students learn from each other. The knowledge and skills acquired in earlier courses work into the design of an engineering system that is open-ended and incorporate practical constraints, in a multi-disciplinary setting. The interests of the students are taken into account in the design of the project, which occurs during the prior fall semester, to motivate them to try novel approaches, make mistakes, experiment, and evaluate alternative solutions.to enhance the student’s learning experience. Engineering standards take the form of current device specifications or data sheets obtained from the manufacturer, usually through on-line Web pages. A typical project usually involves some part fabrication that is done in the CEID using a 3D printer of laser cutter. Before using these tools, students receive instructions on safety, use, and part selection for implementing their design. Students are monitored by the EE laboratory support staff, Kevin Ryan, who was a EE design engineer.

Cooperative Education.

The Yale Electrical Engineering Program does not allow cooperative education to satisfy curricular requirements.

Available Material for review during visit.

During the virtual visit by the ABET reviewer, the textbook and sample student work will be available for each required course. The EE Department will coordinate with the EE Reviewer as to the most suitable method of transferring this information.

B. Course Syllabi

Appendix A contains the syllabus for each course used to satisfy the mathematics, science, and discipline-specific requirements required by Criterion 5.

Table 5-1 Curriculum for Electrical Engineering – Bachelor of Science

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)* Math & Basic Sciences	Engineering Topics; Check if Contains Significant Design (√)	Other	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]
First Year Fall						
MATH 112a, Calculus I	R	3			F19, F18	139
Humanities/Social Science Electives	E			9		
First Year Spring						
MATH 115b, Calculus II	R	3			S20, S19	267
ENAS 130b, Intro to Computing	R		3		S20, S19	66
EENG201b, Intro to Computer Engineering	R		3(√)		S20, S19	41
Humanities/Social Science Electives	E			6		
Second Year Fall						
ENAS 151a, Multivariable Calculus for Engineers or MATH 120a, Calculus of Functions of Several Variables	R	3			F19, F18	84
Physics 180a, Advanced General Physics	R	3			F19, F18	277
EENG200a, Intro to Electronics	R		3		F19, F18	61
ENAS 194a, Differential Equations and Applications	R	3			F19, F18	76
Humanities/Social Science Elective	E			6		
Second Year Spring						
Physics 181b, Advanced General Physics	R	3			S20, S19	230
Math 222b, Linear Algebra	R	3			S20, S19	131
Humanities/Social Science Elective	E			6		
Third Year Fall						
EENG202a, Communications, Computation and Control	R		3		F19, F18	22

EENG320a, Semiconductor Device Fundamentals	R		3		F19, F18	9
EENG348a, Digital Systems	R		3 (√)		F19, F18	37
Humanities/Social Science Elective	E			6		
Third Year Spring						
EENG203b, Circuits and Systems Design	R		3 (√)		S20, S19	18
EENG310b, Signals and Systems	R		3		S20, S19	7
Humanities/Social Science Elective	E			6		
Fourth Year Fall						
EENG325a, Electronic Circuits	R		3 (√)		F19, F18	6
S&DS 241a, Probability theory	R	3			F19, F18	
EENG Electives	SE		6			
Humanities/Social Science Elective	E					
Fourth Year Spring						
APHYS 322b, Electromagnetic Waves and Devices	R	3			S20, S19	
EENG481b, Advanced ABET Project	R		3(√)		S20, S19	6
EENG Electives	SE		6			
TOTALS (in terms of semester credit hours) Total must satisfy minimum credit hours		27	42	39		
Minimum Semester Credit Hours		27	42			

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

CRITERION 6. FACULTY

A. Faculty Qualifications

Leadership Responsibilities

At Yale, the Director of Undergraduate Studies (DUS) is responsible for the requirements for completing a major program and the program's curriculum. For the ABET BS EE program the DUS in EE has the leadership responsibility. The DUS meets with all the majors at least once per term to approve schedules and monitor progress. Through student meetings the DUS gets a general impression of the status of the major sentiments. On curricular matters, the DUS must approve all new courses in the major by filling out portions of a course proposal form.

Authority and Responsibility of Faculty

EE faculty have responsibility for teaching technical material that will make our students successful in their engineering pursuits. In addition to teaching the fundamentals that every EE should know, Yale faculty concentrate on the fundamental scientific principles that are the foundations of technology, since these will not change with time. As new technologies come into being, the principles that make them possible and limit the performance are used as applications of the basic scientific principles. Their varying backgrounds allow each professor to bring a slightly different flavor to a course by emphasizing different aspects of the material. Required courses must follow the syllabus and cover topics used in subsequent and elective courses.

Professors of the follow-on course evaluate the level of fundamentals teaching in the required courses and accommodate by varying the amount of review, both less and more. Such accommodations are typically discussed at faculty meetings and appropriate action taken.

Faculty Competencies

The EE curriculum beyond the general fundamental of electrical engineering concentrates in three areas, with relevant sub-areas:

1. Signals and systems
    - Automatic control
    - Sensors data & digital signal processing
    - Communications & information theory
2. Microelectronics & Photonics
    a. Nanostructures
    b. Optical devices
    c. Sensors & novel devices
3. Computer Engineering
    a. Computer networks
    b. Security
    c. Synchronous & asynchronous computer architectures

These areas were selected because of their technological importance, their educational breadth, and the strengths of neighboring departments at Yale. Yale EE faculty are typically prominent researchers in their respective disciplines, and this research activity positively influences the quality of the undergraduate curriculum.

B. Faculty Workload

Faculty

Yale EE faculty all have PhD degrees and all EE courses are taught by EE faculty, with graduate students Teaching Fellows grading student work and holding help sessions.

Most faculty are also active researchers and members of a research group. The typical workload is two courses per year, usually one undergraduate course and one graduate course. Occasionally, faculty will also volunteer to teach an additional seminar or assist in courses for non-science majors. Most faculty also supervise senior projects.

Tables 6-1 and 6-2 summarize the activities of the EE faculty.

Faculty Size

Clearly, the size of the EE faculty is smaller than the typical EE department at other universities. Yale is aware that EE must be selective in its research endeavors while providing a quality educational experience for its undergraduates. Yale faculty members are fortunate to have exceptional students who are eager to learn and take on leadership roles in their future careers. It is a testament to the ingenuity of Yale EE faculty members to be able to successfully balance their teaching responsibility and research activity

Appendix B contains an abbreviated resume for each EE faculty member with the rank of instructor or above.

C. Professional Development

Faculty Development

Yale has been generous with its faculty support programs. These include:

1. Start-up funds that allow a new faculty hire to initiate a research activity at Yale. Larger sums typically go to experimentalists, who require specialized research facilities.

2. Junior faculty fellowships are awarded to faculty to pursue a promising direction in their research during a semester without teaching obligations.

3. Faculty leaves are available to faculty. Triennial leaves with full salary support can be taken one semester after every seven semesters of teaching. Sabbatical year leaves can be taken at half salary support after seven years of teaching.

4. Conference travel grants are available to faculty to travel to a conference each year, if research funds are not available.

5. Matching funds are usually made available to assist faculty in obtaining matching grants.

6. Grants to improve educational methods are offered on a competitive basis by Yale College. These grants are typically less than $10K and are used for course development involving computer software or hardware.

D. Authority and Responsibility of Faculty

Proposal for New Courses and Changes in Existing Courses

The Director of Undergraduate Studies (DUS) currently makes proposals for new courses and for course changes on the online Course Proposal Form (CPF) with the new Web-based curriculum management tool CourseLeaf.

The first part of a course proposal may be completed by a faculty, a department registrar, or any other person with a Yale NetID and password. The DUS is responsible for: verifying that the details of the course are accurately described on the form, completing the DUS section of the form, and for electronically submitting the proposal to the Course of Study Committee. After the proposal is submitted, it is usually included on the agenda of the next meeting of the committee. Course proposals must be submitted in time for the Yale College Faculty to vote on them. (The Yale College Faculty meets on the first Thursday of each month during term-time, except in September and January.)

Also of importance is the Course Proposal Form's section on the nature and amount of work required for a course. The Course of Study Committee has expressed the strong feeling that students in every type of course must have some review of their work and standing in the course by midterm. Such feedback can be provided, for example, by a midterm test, by a paper due by midterm, by the evaluation of an oral presentation during the term, or by some other similar arrangement.

The key to the success of the committee's work is the care and clarity with which directors of undergraduate studies propose new 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 or program. 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).

Changes in Existing Courses

Besides new courses, any already existing course that undergoes a significant change must be submitted on the Course Proposal Form.

Teaching and Course Evaluation

In order to assist instructors in improving their courses and their teaching as well as to improve education in Yale College in general, the Yale College Faculty, on the recommendation of the Committee on Teaching, Learning, and Advising, expects 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 in order to have early access to online reports of term grades from the Registrar's Office.

Role of Faculty in the attainment of Student Outcomes

Yale SEAS has implemented an Excel spreadsheet for assessing ABET Student Outcomes (the "SAGS" in Criterion 3) and the short ABET form used for the ABET-EE program.

In the SAGS, faculty input grades for each assignment (exams, homework, etc.), 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 cut off percentages. The spreadsheet then calculates the percent of each ABET Student Outcome that is achieved by this course. Finally, the SAGS produces a graph and a table that summarizes the levels of performance for each ABET outcome in the course. The analysis of each course is then combined with that from other required courses in the ABET-EE curriculum to establish an overall measure of the program's ability to achieve Student Outcomes.

In the short ABET form, instructors of ABET-EE required courses give an objective opinion on the number of ABET students that have achieved each outcome every two years, at the end of the semester. In the third and fourth years of the ABET-EE program, the average number of ABET-EE students in the ABET-EE required course in the last six years has been six. With such small numbers, the EE faculty know each student individually, allowing them to gauge outcome achievement objectively. By the third year, students who decide to major in the ABET-EE program have typically bonded into a self-supportive group of talented students that is a pleasure to teach and mentor. Even in classical courses taught in EE (systems in EENG 310, semiconductors in EENG320, electronic circuits in EENG325, digital systems in EENG348) it is not uncommon for Instructors to *learn* novel approaches from the questions and projects of these bright students.

Table 6-1. Faculty Qualifications

Faculty Name	Highest Degree Earned- Field and Year	Rank [1]	Type of Academic Appointment[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
Leandros Tassiulas	Ph.D.	P	T	FT	2	28	6	None	M	M	L
Jung Han	Ph.D.	P	T	FT		20	20	None	M	H	M
Roman Kuc	Ph.D.	P	T	FT	7	>40	>40	None	L	M	L
Tso-Ping Ma	Ph.D.	P	T	FT	0	>40	>40	None	L	L	L
A. Stephen Morse	Ph.D.	P	T	FT	2	>40	>40	None	H	H	L
Kumpati Narendra	Ph.D.	P	T	FT	0	>40	>40	None	H	H	M
Mark Reed	Ph.D.	P	T	FT	7	30	30	None	H	M	H
Hong Tang	Ph.D.	P	T	FT	0	14	14	None	H	H	L
J. Rimas Vaisnys	Ph.D.	P	T	FT	0	>40	>40	None	L	H	L
Rajit Manohar	Ph.D.	P	T	FT	2	25	3	None	L	L	M
Fengnian Xia	Ph.D.	P	T	FT	8	7	7	None	L	L	L
Amin Karbasi	Ph.D.	ASC	TT	FT	0	6	6	None	M	M	M
Jakub Szefer	Ph.D.	ASC	TT	FT	0	7	7	None	M	M	M
Wenjun Hu	Ph.D.	AST	TT	FT	3	6	6	None	L	M	L
Priya Panda	Ph.D.	AST	TT	FT	0	1	1	None	M	M	M
Richard Lethin	Ph.D.	A	NTT	PT	20	15	15	None	M	H	H

1. Code: P = Professor ASC = Associate Professor 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.

Table 6-2. Faculty Workload Summary

Faculty Member (name)	PT or FT[1]	Classes Taught (Course No./Credit Hrs.)	Term[6]	Year[2]	Program Activity Distribution[3] Teaching	Research or Scholarship	Other[4]	% of Time Devoted to the Program[5]
Leandros Tassiulas	FT	EENG 452: Internet Engineering	F	2019	30%	30%	40% (chair)	100%
		ENAS 963: Network Algorithm & Stochastic Opt	SP	2020				
Jung Han	FT	On Leave	F	2019	50%	50%		100%
		EENG 408: Electronic Materials	SP	2020				
Roman Kuc	FT	EENG 481: Advanced ABET Projects	SP	2020	50%	50%		100%
		EENG 101:The Digital Information Age	F	2019				
Tso-Ping Ma	FT	EENG 401: SemicondSiliconDevices & Technology	SP	2020	25%	75%		100%
		On Leave	F	2019				
A. Stephen Morse	FT	EENG 442: Linear Systems	F	2019	25%	25%	50% (leave)	50%
		On Leave	SP	2020				
Kumpati Narendra	FT	EENG 436: Systems and Control	F	2019	50%	50%		100%
		EENG 310: Signals and Systems	SP	2020				
Mark Reed	FT	EENG 320: Intro to Semiconductor Devices	F	2019	40%	40%	20% (DUS)	100%
		EENG 200: Intro to Electronics	F	2019				
Hong Tang	FT	EENG 203: Circuits and Systems Design	SP	2020	20%	30%	50% (DGS) (leave)	60%
		On Leave	F	2019				
J. Rimas Vaisnys	FT	EENG 450: Applied Digital Signal Processing	F	2019	50%	50%		100%
		EENG 397: Math Methods In Eng.	SP	2020				
		ENAS 500: Math Methods 1	SP	2020				
Jakub Szefer	FT	EENG 201: Intro to Computer Engineering	SP	2020	50%	50%		100%
		EENG 428: Cloud FPGA	F	2019				
Fengnian Xia	FT	EENG 325: Electronic Circuits	F	2019	50%	50%		100%
		EENG 406: Photovoltaic Energy	SP	2020				
Wenjun Hu		EENG 202: Comm, Comp, Control	F	2019	50%	50%		100%
		EENG 451: Wireless Tech & IoT	SP	2020				
Priya Panda	FT	ENAS 940: Neural Networks & Learning Sys	F	2019	50%	50%		100%

		On Leave	SP	2020				
Rajit Manohar	FT	EENG348: Digital Systems	SP	2020	50%	50%		100%
		EENG 426: Silicon Computation	F	2019				
Amin Karbasi	FT	EENG 400: Dynamic & Discrete Optimization	F	2019	50%	50%		100%
		ENAS 496: Stochastic Processes	SP	2020				
Richard Lethin	PT	EENG 449: Computer Architectures & AI	F	2019	100%			100%

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

CRITERION 7. FACILITIES

A. Offices, Classrooms and Laboratories

Not only has 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 the School of Engineering & Applied Science (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 Electrical Engineering are all provided with an office in either Becton Center or Dunham Laboratory. In addition, Program Faculty are supplied with space for experimental and computational research laboratories in Becton Engineering Center (Profs. Han, Kuc, Ma, Tang, Reed, and Xia), Dunham Laboratory (Profs. Morse, Narendra, Manohar, Szefer, and Panda), and "17 Hillhouse" (Profs. Tassiulas, Karbasi, and Hu).

The Department of Electrical Engineering is supported by three administrative assistants. Vanessa Epps is located in Becton 509, Pam DeFillipo in Dunham 402, and Nehemiah Hodges is located in Becton 507. These individuals assist in supporting the Faculty's administrative needs including academic record keeping 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 in the common area of the Dean's Office for faculty and students to print posters for projects, activities, and presentations.

Teaching Assistants 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 location, 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 provided to help faculty plan, facilitate and deliver on-line content in future courses.

Two other Yale University facility investments deserve to be noted from their magnitude, proximity, and effect on Yale's engineering program. The Tsai Center for Innovative Thinking at Yale (Tsai CITY) will open in September 2020 and serve, in partnership with two School of Engineering & Applied Science venues as "Yale's Innovation Corridor." Tsai CITY is an independent center that fosters innovation, entrepreneurship and problem solving for Yale students. Housed in a new 10,000 square foot building in the middle of Yale's engineering campus, staffed with 16 employees, and under the operational/organizational structure of the Provost's Office, Tsai CITY provides co-curricular and extracurricular support to students who form teams, partnerships and ventures to apply innovation, entrepreneurship and leadership skills to solve problems and create change. While not all problems have a technology focus, the establishment of Tsai CITY on the engineering campus greatly benefits engineering students develop these aspects of their professional and personal pursuits.

In a similar vein, though not an engineering facility, the Schwarzman Center will open this Fall as a center for student life and the arts at Yale. Designed to draw together students, faculty, and alums from all of Yale's schools and colleges, the Schwarzman Center is open to all at Yale and provides spaces for meeting, dining, and networking. In addition to these functions, the center will serve as a venue for thought-provoking cultural programs throughout the year. Of note is the fact that the center adjoins the engineering campus, with its location and openness of use thereby being of immediate benefit for engineering students to use for curricular and extracurricular uses such as problem set gatherings, lab group discussions and engineering club meetings.

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 408 & Becton Engineering Center 508) and one 20-seat seminar room (Mason Laboratory 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 50-seat classroom (Mason Laboratory 211), a 100 seat classroom (Dunham Laboratory 220), and five 20-seat classrooms (Becton Engineering Center C031, 102, and 104, Mason Laboratory 104, and Dunham Laboratory 102). A 20 station Computer Classroom is located in Dunham Laboratory 120D, and a 52 computer station classroom is located in the basement of 17 Hillhouse.

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

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). 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 90-seat Teaching Enhanced Active Learning (TEAL) classroom where students sit at 8-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 200-level courses, EENG 200, 201 and 202, have used these rooms for their lectures.

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 shop, wood shop and wet lab, as well as the assistance of four staff members (2 PhD level, 2 BS level) that manage all aspects of the CEID. The Director of the CEID is Deputy Dean Vince 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 first year engineering course, a course on the design of new products, and a course on the design of musical instruments. CEID staff trained students to use its 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, from 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 careers paths. In addition to these activities, 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.

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 IEEE, 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 a popular student destination for collaboration on class work with students regularly meeting in the Center to work on problem sets, study and prepare for exams.

The CEID staff actively collaborate with similar groups 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 from faculty and staff at other academic makerspaces. In October 2019, the CEID hosted the International Symposium on Academic Makerspaces to bring 350 members (from across the world) of his professional society together for 3 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. The first function is to hold classes. Over the period 2019-2020, these classes have included Making It (ENAS 400), Medical Device Design and Innovation (MENG/BENG 404), Introduction to Engineering, Innovation, and Design (ENAS 118), Physics of Music and Instrument Design (ENAS 220), and Green Engineering and Sustainable Design (ENAS 360). The openness of the classroom in proximity to the studio space makes it an excellent space for design courses, where students can learn the lecture material and readily put it into practice in the studio space. The Electrical Engineering program uses this space for ABET senior project presentations.

Its second function is to serve as a space for guest lecture series and employment networking gatherings, typically schedule on Monday evenings. The third use of this classroom 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 CEID classroom 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 classroom lecture space, there are 5 reconfigurable conference rooms located on the mezzanine, each containing a large LCD computer and teleconference capabilities and plenty of white board space. These can also be used for classes in addition to meetings, small group discussions, student groups, and study time. These spaces can also be reserved online and are available 24/7 as well. The Electrical Engineering program uses this space for ABET senior poster presentations.

Teaching Laboratory facilities relevant to the Yale Electrical Engineering Program: Course Teaching Laboratories

A description of the Electrical 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 and Electrical Engineering Teaching Facility.

Table 7-1: Laboratory Facilities of the Department of Electrical Engineering

Physical Facilities (Building and Room No.)	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 project (EENG 200, EENG 201, EENG 203, EENG 348, EENG 481)	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

The **Linda and Glenn H. Greenberg Engineering Teaching Concourse** (GETC) 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 and wheeled into the labs at the appropriate point in the semester. The space also includes an office for the School’s Teaching Support Staff (Mechanical Engineering Design Advisor Glenn Weston-Murphy, Electrical Engineering Design Advisor Kevin Ryan and Research Scientist Katherine Schilling, PhD).

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 white-boards) to enable these three labs to be used in alternate configurations. Three of the dry labs are outfitted advanced electronics stations (computer, oscilloscope, power supply, function generator, and support tools) 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 for infrequent use, with the lab benches generally left open to accommodate open-ended project courses and general lab instruction. 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 the 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 72 new computers, electronics, experiment stations, and fabrication tools (detailed in Appendix D), demonstrate Yale's significant commitment of resources to support undergraduate engineering education.

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

The SEAS Machine Shop assists students, staff, and faculty on original educational and research projects by conceiving, designing, and constructing apparatus and instrumentation for the support of research and instructional projects. The SEAS Machine Shop equipment consists of basic machine shop instrumentation 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 x 1 ft cutting area).

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 provides professional technical support for research and educational projects, studies and experimentation. He also analyzes, advises and assists students, staff, and faculty on original educational and research projects while conceiving, designing, and constructing apparatus and instrumentation for the support of research and instructional projects.

Teaching Laboratory Facilities relevant to the Yale Electrical 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 4 major spaces: Studio Space, Machine and Metal Shop, Wood Shop, and Wet Lab. 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. A list of equipment in the Studio is presented in Table 7-2.

Table 7-2: Equipment Located in the CEID Studio

Equipment	Amount	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+	3	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
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	Sheer
DI-ACRO Model No. O2TN	1	Notching machine

In addition to this equipment, the CEID electronics stations (2 stations) each have 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 equipment, circuit boards, Arduino hardware and electronic components (resistors, capacitors, transistors op amps, LEDs, servos, and sensors).

The **CEID Metal and Wood Shops** are accessible to students only with staff supervision. Students can use this space for many projects and classes. Available tools and equipment are listed in Table 7-3.

Table 7-3: Equipment Located in the CEID Machine and Wood Shops

Machine Shop Equipment	**Amount**	**Description**
ULS Laser Cuter 4' x 2'	1	Laser Cutter
Tormach PNC 440	1	CNC Mill
Jet VBS-2012	1	Vertical Bandsaw
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	Mill Machine
Clausing M300	2	Lathe

Wood Shop Equipment	**Amount**	**Description**
Shopbot PRS Alpha	1	4' x 4' CNC milling/routing
ShopBot Desktop	1	2' x 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

The **CEID Wet Lab** has equipment that is designed to serve a variety of different 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 limited to: microscopes, transilluminaro, 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 paper microfluidics more suited to diagnostics for the developing world. Equipment for this purpose includes, but not limited to: vacuum pump and desiccator, microscopes, fiber optic illuminators and fume hood. A third purpose is to house instruments that are used to remove support material from parts produced by CEID 3D printers.

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 and developmental biology; ecology and 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 lab, as well as new lounge areas and student lockers. These labs are used by engineering students for labs in chemistry and physics. These improvements demonstrate Yale's continued investment in undergraduate educational facilities.

B. Computing Resources

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

In the computer resource center in Dunham Laboratory 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 (16 computers) which is accessible when not being used for instruction.

The networked computers in Dunham Laboratory 120 (as well as 17 Hillhouse and in the CEID) are all outfitted with the following software: *Solid Works*, *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 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 available 24/7 with a Yale ID card.

The Teaching Enhance Active Learning Classroom 101 (TEAL) 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, and a projector (HD 1920x1080), and white boards. 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 to hold lectures and presentations. Study tables with additional seating for 10 and whiteboards are available for individual or group study and research. The room houses a printer/scanner/copier.

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 conductivity to software installation can be obtained by contacting IT support via phone or email. Their automated ticket and scheduling system ensures that all IT issues are resolved promptly.

Undergraduates engaged in computational research in the Electrical 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 and 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 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 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 Program Faculty, staff, and teaching assistants guide students regarding the safe use of laboratory equipment. The Professors along with the Teaching Fellows (PhD students serving as laboratory assistants), 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.

CEID Guidance

To be a member of the CEID and use its 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 protection equipment (eye wash, fire extinguisher use, etc.). In addition, there are formal trainings for the metal and wood shop and 3-D printers. Staff members (2 PhD level, 2 BS level) are available full-time from 9am-6pm and undergraduate staff is available from 6-9pm. Access for the 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 the Yale ITS services and they are remotely monitored and periodically upgraded.

For the facilities that are under the control of the Electrical 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.

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 (Information Technology Services), and disk image software is upgraded annually. For the SEAS Machine 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 the School of Engineering & Applied Science 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 fiscal year 2019, the engineering librarian conducted 24 orientation and instruction sessions with 380 participants. In addition, library staff offers support and training for bibliographic management software, electronic laboratory notebooks, GIS, and managing data.

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, Sterling Memorial Library. Science materials are also housed in the newly renovated Center for Science and Social Science Information (CSSSI), which includes collections in physics, biology, and chemistry; the Mathematics Library; the Geology 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. Twenty-four hour per day study space is provided at CSSSI. 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 Web 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 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, ACM, American Chemical Society, American Physical Society, the American Society of Electrical 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 Electrical 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 and Safety (EHS) to ensure that all instructional equipment conforms to University safety standards. A representative from the School of Engineering and Applied Science 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. 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 Electrical Engineering is led by the Chair, who presides over all departmental matters, the Director of Undergraduate Study (DUS), who presides over undergraduate affairs, and the Director of Graduate Study (DGS), who presides over graduate affairs. Major decisions, such as 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 grant course substitutions to students, but often consults other EE Faculty before doing so.

The Chair is appointed by the Yale President, following consultation with SEAS and other EE Faculty. The term of the appointment is three years. The Chair then appoints the DUS and the DGS, following consultation of the EE Faculty.

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.

An Advancement Committee for Engineering (ACE) provides guidance to the Dean on long range strategic planning and participates in the tenure and promotion process as a SEAS-wide voice on individual cases. Finally, a SEAS Space Committee (consisting of the four Chairs and facilitated by the Deputy Dean of Engineering) reviews all space allocations within the School. While space within each individual Department is controlled and assigned by the Department Chair, the SEAS Space Committee provides guidance to the Dean regarding new space allotted to the School (such as in 17 Hillhouse) and helps coordinate space issues that involve multiple Departments, such as reassignment of research labs to accommodate growing research programs and new faculty appointments.

This leadership structure is similar to that in other departments across Yale and has served the EE Department and the EE-ABET Program well for many years. This structure includes a strong working relationship with the Provost via a number of channels including direct access of the EE Chair to the Provost (and the Deputy Provost for Science and Engineering) as well as SEAS-wide representation to the Provost (and the Deputy Provost for Science and Engineering) through the Dean of SEAS. 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 funds for operations in the EE. Additional funds are made available from discretionary accounts within the Department. We believe the financial resources to be sufficient to accomplish the Program Educational Objectives and ensure continuity of the EE Program.

In addition to these sources of funding, Program Chairs work with the SEAS Dean on other needs. If the fund request exceeds the amount in the Dean's budget, the Dean negotiates with the Provost's Office for additional funds. The Provost also controls a Science Development Fund, which has funds to address unusual opportunities for enhancing the quality of 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. 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 SEAS Dean.

Funding levels are adequate to meet the programmatic needs of the EE Department. Table 8.1 provides a three-year history of funding levels specific to support of the EE Department's teaching program.

Table 8-1: Electrical Engineering Teaching Program Funding

Electrical Engineering	**FY17**	**FY18**	**FY19**	**FY20**
Faculty Salaries (burdened)	2,537,268	2,428,743	2,575,796	2,742,323
Allocated Support Staff Wages (burdened)	313,387	291,100	318,720	321,889
Operating	21,000	21,000	21,000	21,000
Allocated Support for Teaching Programs	18,561	33,969	21,785	48,633
Seminars	15,000	15,000	15,000	15,000
Discretionary	25,000	25,000	25,000	25,000
1x Teaching Equipment Funding	17	-	-	45,481
Teaching Assistants	455,938	467,813	479,063	490,938
Total	3,386,171	3,282,625	3,456,364	3,710,263

Regarding institutional teaching support in the form of TAs, teaching workshops and other resources, these programs are managed through a variety of mechanisms at Yale including the EE Department, SEAS, the Graduate School for Arts and Sciences, and the Provost's Office.

Teaching experience is regarded as an integral part of the graduate training program at Yale University, and all Engineering graduate students are required to serve as a Teaching Fellow for one term, typically during year two. Teaching duties normally involve assisting in laboratories or discussion sections and grading papers and are not expected to require more than ten hours per week. Graduate students are not permitted to teach during the first year of study.

Generally, courses in engineering are supported with one Teaching Fellow (designated as a TF2, not to exceed 10 hrs/week) for every 20 students in a course or lab. Courses (without a lab) with an enrollment less than ten students are not awarded a Teaching Fellow. Funds for the Teaching Fellow program are provided by the Yale Graduate School.

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 to which resources are provided to maintain and upgrade the infrastructure, facilities and equipment in the program, the EE Department Chair has access to a large support network to effect change. At one level, SEAS works with the Provost's Office to acquire maintain and upgrade facilities and equipment. The Greenberg Engineering Teaching Concourse is one example of a supportive process to advance local improvements through this process. In this case the improvement was initiated to the Provost by SEAS. 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. Equipment is maintained by the Provost-managed Teaching Fund described in a previous paragraph.

On another level, the EE Department Chair has access to a support and maintenance network within SEAS. Such support is coordinated through the Business Office for routine maintenance of infrastructure and for minor renovations. Such work may be accomplished using SEAS 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 EE Program and its students, resources have been adequate to attain the Student Outcomes, as detailed in Chapter 4.

C. Staffing

Our world-renowned and diverse EE 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 SEAS. The EE Department and SEAS 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.

Our team consists of a computer support specialist, teaching lab specialists, financial management, director of communications, program manager and analyst, Dean, Deputy Dean, Assistant Dean, Dean's support team and several administrative assistants. In addition to the EE Faculty, the following individuals within SEAS provide direct support the EE-ABET Program.

1. Technical support:
    - Teaching lab support specialists (Glen Weston-Murphy, Kevin Ryan, Nick Bernardo) as well as CEID support
    - Computer support specialist (IT Services)
    - Student computing assistants (IT Services)

2. 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 & Outreach (William Weir)
    - Lead Administrator (Denny Kalenzaga)
    - Facilities Operations (Andy Morcus)

3. Department of Electrical Engineering Administrative Support
    - Administrative Associate to Program Chair (Vanessa Epps)
    - Administrative Assistants (Pamela DeFelippo and Nehemiah Hodges)

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 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 SEAS Dean, or by an appointments committee. Appointments to the rank of assistant professor are reviewed by the SEAS Dean. Appointments to the ranks of associate professor on term or with tenure and to 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 issued 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. Funds for travel assistance 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 travel to professional meetings at which the faculty is reading a paper or chairing a session. 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. In special cases persons holding full-time Adjunct appointments are eligible. To qualify for a travel grant, the faculty member must actively participate in the meeting by reading a paper, 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 or delivering a paper 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 form teaching duties during their first semester 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. Full professors are eligible for triennial, one-semester leaves at full salary. As established in Yale's Tenure and Appointments Policy, assistant professors are eligible 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

A. Program Criteria Discussion

Table C-1 lists the Electrical Engineering professional criteria required by ABET and the required courses that contribute to each criterion. The design criterion is met by courses that include a design component, which include courses near the beginning of the EE Program (EENG203), in the middle (EENG325, EENG348), and terminate in the capstone design project (EENG481).

Table C-1 EE Professional Criteria

Professional Criterion	Course(s) Satisfying Outcome
Knowledge of probability and statistics	S&DS 241 Probability Theory (Stat & Data Science)
Knowledge of mathematics through differential and integral calculus.	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, or ENAS 151 Multivariable Calculus for Engineers
Basic science	PHYS 180 Advanced General Physics I. PHYS 181 Advanced General Physics II. APHY 322 Electromagnetic Waves and Devices.
Computer Science	ENAS 130 Intro to Computing for Eng EENG201 Intro to Computer Eng EENG202 Communication, Computation & Control EENG348 Digital Systems
Engineering Science	EENG200 Intro to Electronics. EENG201 Intro to Computer Engineering. EENG202 Communication, Computation & Control EENG203 Circuits and System Design. EENG310 Signals and Systems. EENG320 Semiconductor Device Fundamentals. EENG325 Electronic Circuits. EENG348 Digital Systems. EENG481 Advanced ABET Projects.

Table C-1 (continued)

Advanced Mathematics • Linear Algebra	• MATH 222 Linear Algebra with Applications
• Differential Equations	• ENAS 194 Ordinary and Partial Differential Equations with Applications
• Complex variables	• EENG200 Intro to Electronics. • EENG202 Communication, Computation & Control. • EENG203 Circuits and System Design • EENG310 Signals and Systems
• Discrete Math	• EENG202 Communication, Computation & Control • EENG310 Signals and Systems • EENG348 Digital Systems

Appendix A – Course Syllabi

Contents:

1. Course number and name: MATH 112: Calculus of Functions of One Variable

2. Credits and contact hours: 3.0 credits, 3 hours/week

3. Instructor's name: Thomas Hille, Lecturer for Department of Mathematics

4. Textbooks (title, author, publisher, year): *Calculus: Early Transcendentals*, 8^{th} edition, by James Stewart, published by Cengage Learning. (Chapters 2-5 and 9)

a. Supplemental materials:

- The Math 112 website in Canvas. Announcements, homework and course materials will be available there in their most updated versions. Please be sure to check it regularly.
- Ximera, homework modules available through canvas.

5. Specific course information:

a. Brief description of the content of the course (catalog description):

The objective of the course is to study continuous change of functions. We will discuss:

- Continuity - whether a function's output changes abruptly or not as you perturb the input.
- The derivative - a measure of the rate at which the output of a function changes as you perturb the input; and
- The integral - a measure of the area under the graph of a function.

For functions of one variable.

b. Prerequisites or co-requisites for course: To succeed in this course, you should have a firm grounding in algebra and precalculus mathematics. Almost all students will have had a calculus course in high school, but no prior acquaintance with calculus will be assumed. Before you enroll in Math 112, you must place into the course on the math department's placement exam.

c. Prerequisite, required, or elective course: Required

6. Specific goals for the course:

a. Specific outcomes of instruction: We will study these objects abstractly (using the language of limits), geometrically, and via some physical interpretations. Emphasis will be placed on acquiring an understanding of the concepts that underlie the subject and on the use of those concepts in problem solving.

b. Which student outcomes listed in Criterion 3 are addressed by this course:
(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: The objective of Math 112 is to introduce the notions of derivative and of definite integral for functions of one variable.

- 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: 3.0 credits, 3 hours/week

3. Instructor's name: Aaron Calderon, Lecturer for Department of Mathematics

4. Textbooks (title, author, publisher, year): *Calculus, Early Transcendentals*, 8th Edition by James Stewart.

a. Supplemental materials: N/A

5. Specific course information:

a. Brief description of the content of the course (catalog description):
In Math 115, we take complex problems and break them up into simpler ones. For instance, we can approximate the length of a winding curve by chopping it into pieces that look roughly like straight lines. By splitting a problem into smaller and smaller parts, we get better and better approximations for the solution. When we compute the LIMIT of these approximations, we get the exact answer. Otherwise, we bound the ERROR in our approximation.

b. Prerequisites or co-requisites for 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: Required

6. Specific goals for the course:

a. Specific outcomes of instruction:
Over the semester, we will develop techniques for solving problems in geometry, economics, biology and physics. These techniques include Riemann sums, integration, Taylor series, and parametric and polar equations. We will also appreciate the beautiful way these ideas fit together within the theory of calculus, the mathematics of change.

b. Which student outcomes listed in Criterion 3 are addressed by this course:

- (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:

Math 115 focuses on the relationship between net changes and rates of change.

- Find antiderivatives.
- Approximate definite integrals and analyze the error in those approximations.
- Determine whether infinite series converge or diverge.
- Represent functions with Taylor series.
- Compute lengths, areas, and volumes of geometric objects.
- Model curves using parametric and polar equations.

1. Course number and name: MATH 120: Calculus of Functions of Several Variables

2. Credits and contact hours: 3.0 credits, 3 hours/week

3. Instructor's name: Marketa Havlickova, Senior Lecturer in Mathematics

4. Textbooks (title, author, publisher, year): *Multivariable Calculus: Early Transcendental,* 8th edition, James Stewart, Thompson.

a. Supplemental materials: N/A

5. Specific course information:

a. Brief description of the content of the course (catalog description):
In Math 120, we aim to generalize the main concepts from single-variable calculus to a higher-dimensional setting. We will look at the geometry of three-dimensional (and sometimes higher dimensional) objects and the calculus of functions of several variables.

b. Prerequisites or co-requisites for course:
To take Math 120, you must have either passed Math 115 or Math 116 at Yale or achieved a placement of Math 120 from the Math Placement Test

c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

a. Specific outcomes of instruction: In Math 120, students will learn:

- 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; applications.
- Multiple integrals, with applications.
- Divergence and curl.
- The theorems of Green, Stokes, and Gauss.

b. Which student outcomes listed in Criterion 3 are addressed by this course:
(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: Some of the topics we will study include:

- Vector geometry in three dimensions
- Vector-valued functions and parametrized curves
- Scalar functions of multiple variables
- Partial derivatives
- Gradients and directional derivatives
- Line integrals
- Green's Theorem,
- Curl and divergence of vector fields,
- Parametrized surfaces
- Surfaces integrals,
- Stokes' Theorem
- Cylindrical and spherical coordinates and the Divergence Theorem.

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

2. Credits and contact hours: 3.0 credits, 3 hours/week

3. Instructor's name: Yariv Aizenbud, Asst Professor of Department of Mathematics

4. Textbooks (title, author, publisher, year): *Linear Algebra its Applications* by Gilbert Strang, 4th edition.

5. Specific course information:

   a. Brief description of the content of the course (catalog description):
      This course is an introduction to the subject of Linear Algebra, a common language applied to a wide variety of real-world situations involving many variables. The concepts of linear algebra are extremely useful in physics, economics, social sciences, natural sciences, engineering, and data analysis (e.g. Google's search algorithm).

   b. Prerequisites or co-requisites for course: MATH 115 or equivalent

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

   a. Specific outcomes of instruction: The goal is not only to teach about linear algebra itself, but to use it as a prototype of mathematical thinking.

   b. Which student outcomes listed in Criterion 3 are addressed by this course:
      (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: Math 222 will blend applications of the subject to these other areas with computational aspects, and a gentle introduction to the main conceptual ideas.

Topics of Math 222 include:

- Vectors and matrices
- Linear equations and Gaussian elimination
- Inverses, transposes, and permutations
- Vector spaces
  - Linear Independence
  - Nullspace, rank
  - Linear Transformation
- Orthogonality, projections, least squares, Gram-Schmidt
- Determinants
- Eigenvalues, Diagonalization, Similar matrices
- Singular value decomposition

1. Course number and name: S&DS 241 – Probability Theory

2. Credits and contact hours: 3.0 credits, 3 hours/week

3. Instructor's name: Yihong Wu and Winston Lin

4. Textbooks (title, author, publisher, year): Introduction to Probability, Charles Grinstead abd J. Laurie Snell, Second Edition.

   a. Supplemental materials: N/A

5. Specific course information:

   a. Brief description of the content of the course (catalog description):

   Introduction to probability theory. Topics include probability spaces, random variables, expectations and probabilities, conditional probability, independence, discrete and continuous distributions, central limit theorem, Markov chains, and probabilistic modeling.

   b. Prerequisites or co-requisites for course: MATH 120 or equivalent

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

a. Specific outcomes of instruction: S&DS241 focuses on probability theory and tends to emphasize mathematical developments more. S&DS241 feels more like a math class.

   a. Which student outcomes listed in Criterion 3 are addressed by this course:

   (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:

Topics include probability spaces, random variables, expectations and probabilities, conditional probability, independence, discrete and continuous distributions, central limit theorem, Markov chains, and probabilistic modeling.

1. Course number and name: PHYS 180 University Physics I

2. Credits and contact hours: 3.0 credits, 4 hours/week

3. Instructor's name: Adriane Steinacker, Senior Lecturer Department of Physics

4. Textbooks (title, author, publisher, year): *Fundamentals of Physics" by David Halliday and Robert Resnick*, 10^{th} edition. You are completely welcome to use older editions of this book.

a. Supplemental materials: N/A

5. Specific course information:

a. Brief description of the content of the course (catalog description):
Physics provides a framework for constructing complicated systems from simple building blocks or reducing a complex problem to its simplest parts. Acquiring the skill of lucidly thinking through problems is, in my opinion, the most important goal in physics education. As a doctor, you will face situations that require out of the box thinking. As an engineer, you will build on the flawless theoretical concepts to make things work, from microchips to bridges. As a citizen of this planet, you have the right and the duty to be informed and to verify claims. Even in our day-to-day existence, the ability to solve problems can transpire from physics to mundane tasks.

b. Prerequisites or co-requisites for course: Concurrently with MATH 115 and 120 or equivalents. See comparison of introductory sequences and laboratories in the YCPS. 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:
The range of backgrounds and motivations for this course is, by nature, very broad. While the need for mastering Physics at an introductory level is obvious for Physics, Chemistry and Engineering majors, it may appear less so for the Life Sciences or Computer Science. Physics constitutes the foundation on which an understanding of Chemistry and Biology can be built. It explains how the world works on a fundamental level. Beyond this, a solid training in Physics helps develop analytical skills, which are required in every part of our technology and information-based society. More importantly, building and retaining an ability to perform tasks that today are increasingly directed to machines could be of crucial importance in surviving as a species against the rise of artificial intelligence.

b. Which student outcomes listed in Criterion 3 are addressed by this course:

- (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:

Please note that, although this is a classical curriculum, the list of topic may change for a number of reasons. Most often, this happens because one might work faster or more slowly with a specific group of people. It is also possible that one topic not mentioned below could be of interest to a group of students, or I might find it appropriate to introduce it in a given context.

1) Kinematics: velocity, speed, average and instantaneous velocity and speed, uniform motion in one dimension, motion with constant acceleration, average and instantaneous acceleration, position-time, velocity-time and acceleration-time dependence; Reading y-t, v-t and a-t graphs, examples of motion in one dimension, including free-fall (classes 1, 2, 3).
2) Motion in two and three dimensions. Addition and subtraction of vectors, vector components and unit vector notation, examples. Interpreting y-x graphs, analyzing motion in two dimensions on the example of the projectile motion, graphing trajectories (Class 4, 5).
3) Uniform circular motion, centripetal acceleration (Class 5).
4) Relative motion (Class 6).
5) Dynamics: Forces, Newton's Laws, examples of forces in mechanics including Hooke's Law, projecting forces, free-body-diagrams, centripetal force, combined centripetal force and normal force examples Friction (Class 7, 8).
6) Friction and Drag (Class 9).
7) Energy, Power, Work. Kinetic and gravitational potential energy, conservation of mechanical energy (Class 10). Work and the energy-work theorem, the scalar product, work done by the elastic force, elastic potential energy (Class 11). Conservative and non-conservative forces, potential energy curves (Class 12)
8) Collisions, momentum and momentum conservation (Class 13).
9) Center of Mass and applications (Class 14).
10) Rotational Motion: Angular velocity and acceleration, kinematics of motion with constant angular acceleration, relationship between the linear and angular velocity and acceleration (Class 15).
11) Rotational Dynamics: Torque, the cross product, moment of inertia (Class 16)
12) Rotational kinetic energy, angular momentum, conservation of angular momentum (Class 17, 18).
13) The Universal Gravity: Law of Gravity, orbits, applications (Class 19, 20)
14) The harmonic oscillator: Analyzing the motion of an object tied to a horizontal and vertical spring, equivalence between uniform circular motion and harmonic motion, the simple pendulum, damped and forced oscillations, resonance (Class 21, 22).
15) Properties of waves, transverse waves, effect of boundaries (Class 23)
16) Energy transport, Wave Equation (Class 24)
17) Superposition of linear waves, standing waves (Class 25)
18) Beats and the Doppler Effect (Classes 25 and 26)

1. Course number and name: PHYS 181

2. Credits and contact hours: 3.0 credits, 6 hours/week

3. Instructor's name: Andriane Steinacker, Senior Lecturer Department of Physics

4. Textbooks (title, author, publisher, year): "*Fundamentals of Physics" by David Halliday and Robert Resnick*, 10th edition (chapters 21-33 and 34 or 37). You are completely welcome to use older editions of this book.

a. Supplemental materials: N/A

5. Specific course information:

a. Brief description of the content of the course (catalog description):
Physics provides a framework for constructing complicated systems from simple building blocks or reducing a complex problem to its simplest parts. Acquiring the skill of lucidly thinking through problems is, in my opinion, the most important goal in physics education. As a doctor, you will face situations that require out of the box thinking. As an engineer, you will build on the flawless theoretical concepts to make things work, from microchips to bridges. As a citizen of this planet, you have the right and the duty to be informed and to verify claims. Even in our day-to-day existence, the ability to solve problems can transpire from physics to mundane tasks.

b. Prerequisites or co-requisites for course: Concurrently with MATH 115 and 120 or equivalents. See comparison of introductory sequences and laboratories in the YCPS. 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:
The range of backgrounds and motivations for this course is, by nature, very broad. While the need for mastering Physics at an introductory level is obvious for Physics, Chemistry and Engineering majors, it may appear less so for the Life Sciences or Computer Science. Physics constitutes the foundation on which an understanding of Chemistry and Biology can be built. It explains how the world works on a fundamental level. Beyond this, a solid training in Physics helps develop analytical skills, which are required in every part of our technology and information-based society. More importantly, building and retaining an ability to perform tasks that today are increasingly directed to machines could be of crucial importance in surviving as a species against the rise of artificial intelligence.

b. Which student outcomes listed in Criterion 3 are addressed by this course:
(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:

Please note that, although this is a classical curriculum, the list of topics may change for several reasons. Most often, this happens because one might work faster or more slowly with a specific group of people. It is also possible that one topic not mentioned below could be of interest to a group of students, or I might find it appropriate to introduce it in each context.

1) Introduction and Motivation. Charges, conductors, insulators, the Electrostatic Force (Classes 1 and 2).
2) The Electric Field, probing the Electric Dipole Field (Class 3).
3) The electric field of continuous charge distributions – The parallel plate capacitor (Class 4).
4) Motion of the dipole in a uniform electric field (Class 5).
5) Electric Flux and Gauss's Law (Class 6).
6) Applications of Gauss's Law - Electric field of charge distributions, revisited (Class 7).
7) Electric Potential, electrostatic potential energy (Class 8).
8) Equipotential surfaces, determining the electric field from the potential. The Van de Graaff Generator, breakdown electric field and potential (Class 9).
9) Capacitors, capacitance. Electrostatic energy stored in a capacitor (Class 10).
10) Capacitors in series and parallel. Dielectrics (Class 11).
11) Electric current, resistance, Ohm's Law, resistivity (Class 12).
12) RC circuits. Charging and discharging a capacitor (Class 13).
13) Direct Current Circuits (series and parallel). Power (Class 14)
14) The electromotive force, emf, terminal voltage. Junction, resistance, and emf rule for DC current circuits. The Ammeter and the voltmeter (Class 15).
15) The Magnetic Field: discovery, sources, permeability constant, the Biot-Savart-Law and applications (Class 16).
16) Motion of a point charge in a magnetic field. Lorentz Force. The magnetic force between two parallel wires. (Class 17)
17) The e/m ratio, cyclotron motion, frequency, helical paths, magnetic mirrors. Motion of charges in a uniform electric field. The discovery of the electron and elementary charge (Class 18,19).
18) Torque on a current loop. The magnetic dipole, magnetic moment. The electric motor (Class 20)
19) Magnetic flux, Faraday's Law, induced current and induced emf. Lenz's Law (Class 21)
20) A simple generator. Induction and energy transfer. Inductance, Energy stored in a magnetic field (Class 22).
21) LC and LR circuits (Class 23).
22) Alternate Current Circuits (Class 24, 25).
23) Maxwell's Equations. The speed of light (Class 26).

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

2. Credits and contact hours: 3.0 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:
      (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: 3.0 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:
      (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 201, Introduction to Computer Engineering

2. Credits and contact hours: 3.0 credits, 2 * 50min. lecture + 1 * 2 hour lab

3. Instructor's name: Prof. Jakub Szefer

4. Textbooks (title, author, publisher, year): *David Money Harris and Sarah L. Harris, Digital Design and Computer Architecture, 2nd ed., Morgan Kaufmann, 2012.* (reference text)

a. Supplemental materials: Instructor handouts

5. Specific course information:

a. Brief description of the content of the course (catalog description):

Introduction to the theoretical principles underlying the design and programming of simple processors that can perform algorithmic computational tasks. Topics include data representation in digital form, combinational logic design and Boolean algebra, sequential logic design and finite state machines, and basic computer architecture principles. Hands-on laboratory involving the active design, construction, and programming of a simple processor.

b. Prerequisites or co-requisites for course: None

c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

a. Specific outcomes of instruction:

In this course, students will receive introduction to the theoretical principles underlying the design and programming of computer logic that will ultimately let them design simple processors that can perform algorithmic computational tasks. Starting with data representation in digital form, course goes on to provide students with the ability to design combinatorial and sequential digital circuits for a given algorithmic information processing task. Hands-on labs provides students ability to realize their simple logic and processor designs in field programmable gate arrays (FPGAs).

b. Which student outcomes listed in Criterion 3 are addressed by this course:

(1), (2), (3), (5), (6), (7)

7. Brief list of topics to be covered:

The course covers: representation of information in digital form, boolean algebra, combinational network analysis and design, sequential network analysis and design, finite state machines, basic digital logic and computer systems design, computer organization and control. Selected topics in computer security are also included.

1. Course number and name: EENG 202: Communications, Computation, and Control

2. Credits and contact hours: 3.0 credits, 3 hours/week

3. Instructor's name: Wenjun Hu

4. Textbooks (title, author, publisher, year): Recommended – *Information Science,* David Luenberger, Princeton University Press, 2006.

a. Supplemental materials: course notes

5. Specific course information:

a. Brief description of the content of the course (catalog description):

Introduction to systems that sense, process, control, and communicate. Topics include communication systems (compression, channel coding); network systems (network architecture and routing, wireless networks, network security); estimation and learning (classification, regression); and signals and systems (linear systems, Fourier techniques, bandlimited sampling, modulation). MATLAB programming and laboratory experiments illustrate concepts.

b. Prerequisites or co-requisites for course: MATH 115

c. Prerequisite, required, or elective course: required

5. Specific goals for the course

a. Specific outcomes of instruction: This is an introductory course on signals and systems. The main goals are: (1) develop an appreciation for how "systems" thinking is fundamental to understanding engineered systems. (2) learn to use mathematics as a language for modeling and analyzing engineered systems (3) develop proficiency with MATLAB.

b. Which student outcomes listed in Criterion 3 are addressed by this course:
(1), (3), (6), (7)

6. Brief list of topics to be covered:

This is an introductory course on signals and systems. The course consists of 4 broad sections. Section 1: Communication Systems covers source coding, quantization, and channel coding. Section 2: Network Systems covers network architecture, network routing, wireless networks, and network security. Section 3: Estimation and Learning covers hypothesis testing, classification, clustering, regression, and an introduction to network science. Section 4: Signals and Systems covers signals, linear systems, Fourier series, Fourier transform, the sampling theorem, modulation and filtering.

1. Course number and name: EENG 203 Circuits and Systems Design

2. Credits and contact hours: 3.0 credits, 4.5 hours/week

3. Instructor's name: Hong Tang, Fengnian Xia

4. Textbooks (title, author, publisher, year): *Fundamentals of Electric Circuits, 5th edition* Charles Alexander & Matthew Sadiku, McGraw-Hill, 2012 (reference text)

    a. Supplemental materials: Digilent on-line manual and classroom. http://www.digilentinc.com/NavTop/Classroom.cfm

5. Specific course information:

    a. Brief description of the content of the course (catalog description):

        Introduction to basic circuits including passive and active circuits of first and second order; analysis of practical circuits in time and frequency domain; analysis and implementation of resonators, passive and active filters; analysis of example application circuits. Laplace transform and its application in practical circuits analysis and synthesis; Fourier series and Fourier transform as well as their utilization for circuit analysis.

    b. Prerequisites or co-requisites for course: EENG 200a and 202a; or permission of the instructor

    c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

    a. Specific outcomes of instruction:

        The course covers fundamentals of analog circuits, targeting EE sophomores. The lecture sessions, given twice per week, instruct the fundamentals of electronic circuits and the basic mathematical methods for circuit analysis and synthesis. The lab portion of the course includes the construction and testing of first order and second order circuits, filter implementation, resonator characterization, pcb board assembly and feedback control circuit construction. The course requires understanding of basic circuit theory, detailed analysis of electronic circuits, design and fabrication of circuit board. The student performances are evaluated by homework, lab reports, midterm and final exams.

    b. Which student outcomes listed in Criterion 3 are addressed by this course: (1), (2), (3), (4), (6), (7)

7. Brief list of topics to be covered: first and second order circuits; passive and active circuits, transfer function, bode plots, resonance, passive and active filters, filter applications, Laplace transform and its application for circuit analysis, Fourier series, Fourier transform and its applications.

1. Course number and name: EENG 310 Signals and Systems

2. Credits and contact hours: 3.0 credits, 3.0 hours/week

3. *Instructor's name:* Kumpati. S. Narendra

4. Textbooks (title, author, publisher, year): “Signals and Systems” by Kamen and Heck, Prentice Hall.

   a. Supplemental materials: For topics not contained in the textbook, notes are provided by the instructor.

5. Specific course information:

   a. Brief description of the content of the course (catalog description):

   Concepts for the analysis of continuous and discrete-time signals. Techniques for modeling continuous and discrete-time linear dynamical systems using differential and difference equations and transform methods. Topics include continuous and discrete Fourier analysis, Laplace, Fourier and Z transforms, convolution, sampling, data smoothing, and filtering.

   b. Prerequisites or co-requisites for course: MATH 115, EENG 202, and ENAS 194.

   c. Prerequisite, required, or elective course: Required course.

6. Specific goals for the course

   a. Specific outcomes of instruction:

   The concepts of signals and systems arise in a wide variety of fields and are of fundamental importance in all engineering disciplines and most areas of applied science. The techniques discussed in this course will find application in such diverse areas as speech recognition, biomedical engineering, process control, computer vision, and economic forecasting. The course is designed to provide the student with the necessary background to analyze and synthesize both continuous-time and discrete-time systems. It includes modeling of systems using linear differential and difference equations, their analysis using Fourier series, Fourier Transforms and convolution, and a study of their stability properties and performance using Pole-Zero plots and Laplace and Z-transforms. Introduction to communication theory.

   b. Which student outcomes listed in Criterion 3 are addressed by this course:
   (1), (2), (4)

7. Brief list of topics to be covered:

   1. Signals and Systems. Static and dynamic; invertible; causal; stable; time-invariant, and linear systems.
   2. Impulse response: Discrete-time; Continuous-time.
   3. Introduction to the Laplace Transform.
   4. Transfer functions; Poles and Zeros.
   5. The Z-Transform.
   6. Stability – The Routh-Hurwitz criterion.
   7. The Root Locus. The Nyquist Criterion.

9. The Fourier Transform.
10. Problems in Communication Theory. Modulation; Sampling.

1. Course number and name: EENG320: Intro. Semiconductor Devices

2. Credits and contact hours: 3.0 credits, 75 min. lecture

3. Instructor's name: Prof. Mark Reed

4. Textbooks (title, author, publisher, year): Solid State Electronic Devices, 6th Edition, B. Streetman and S. Banerjee, Prentice Hall, 2005.

    a. Supplemental materials: Instructor handouts

5. Specific course information:
    a. Brief description of the content of the course (catalog description):

    An introductory course to modern semiconductor devices, intended for students majoring in the physical sciences. Topics include crystal structure; energy bands in solids; charge carriers with their statistics and dynamics; junctions, p-n diodes, and LEDs; bipolar and field-effect transistors; and device fabrication. Additional lab one afternoon per other week. Prepares for higher level microelectronics courses.

    b. Prerequisites or co-requisites for course: EENG 200. PHYS 180 and 181 or permission of instructor

    c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

    a. Specific outcomes of instruction:

    Topics include crystal structure; energy bands in solids; charge carriers with their statistics and dynamics; junctions, p-n diodes, and LEDs; bipolar and field-effect transistors; and device fabrication.

    b. Which student outcomes listed in Criterion 3 are addressed by this course:

    (1), (2), (3), (4), (5), (6), (7)

7. Brief list of topics to be covered:

    Crystal structure, quantum mechanics, energy bands, charge carriers, intrinsic carrier concentration, excess carriers, continuity equation, Einstein relations, PN junctions (fabrication, in equilibrium, under bias), JFET, MOSFETs, BJTs, optoelectronics. development of silicon technology.

1. Course number and name: EENG325: Intro. Semiconductor Devices

2. Credits and contact hours: 3.0 credits, 2 * 75min. lecture + 1 * 2 hour lab

3. Instructor's name: Prof. Fengnian Xia

4. Textbooks (title, author, publisher, year): Microelectronic circuits by Sedra and Smith, 8th edition

5. Specific course information:

    a. Brief description of the content of the course (catalog description):
    Models for active devices; single-ended and differential amplifiers; current sources and active loads; operational amplifiers; feedback; design of analog circuits for particular functions and specifications, in actual applications wherever possible, using design-oriented methods. Includes a team-oriented design project for real-world applications, such as a high-power stereo amplifier design. Electronics Workbench is used as a tool in computer-aided design. Additional lab one afternoon per week.

    b. Prerequisites or co-requisites for course: EENG 200

    c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

    a. Specific outcomes of instruction:
    Design of single-ended and differential amplifiers; current sources and active loads; operational amplifiers; feedback; design of analog circuits for particular functions and specifications, in actual applications wherever possible, using design-oriented methods. Includes a team-oriented design project for real-world applications, such as a high-power stereo amplifier design. Electronics Workbench is used as a tool in computer-aided design.

    b. Which student outcomes listed in Criterion 3 are addressed by this course:
    (1), (2), (3), (4), (5), (6), (7)

7. Brief list of topics to be covered:
    This class presents an introduction to critical circuit components in microelectronics, including various diodes and transistors, single-ended and differential amplifiers, current sources and active loads, operational amplifiers, feedback loop, and simple analog circuits for signal amplification and conditioning. Wherever possible, design-oriented methods are emphasized by studying the trade-offs in circuit performance. Examples will be discussed to gain insight in principles of electronic circuits. The impact of the latest developments in nanomaterials on advanced circuits will be briefly covered at the end of this course.

1. Course number and name: EENG 348: Digital Systems

2. Credits and contact hours: 3.0 credits and 2.5 hrs/week lecture

3. Instructor's name: Rajit Manohar.

4. Textbooks (title, author, publisher, year): Slides and handouts/required reading posted on the course web site at http://csl.yale.edu/~rajit/classes/eeng348/

    a. Supplemental materials:

    - Assembly language programming: "Computer Organization: The Hardware-Software Interface" by D. Patterson and J. Hennessy.
    - Real-time systems: "Hard Real-Time Computing Systems: Predictable Scheduling Algorithms and Applications" by G. Buttazzo.

5. Specific course information:

    a. Brief description of the content of the course (catalog description):

       Development of engineering skills through the design and analysis of digital logic components and circuits. Introduction to gate-level circuit design, beginning with single gates and building up to complex systems. Hands-on experience with circuit design using computer-aided design tools and microcontroller programming.

    b. Pre-requisites: EENG 201.

    c. Prerequisite, required, or elective course: Required

6. Specific goals of the course:

    a. Specific outcomes of instruction:
       The student will understand micro-controller-based design of digital systems that combines both software and hardware schematic design. The student will be able to work in a team and develop a working prototype that involves both hardware and software.

    b. Which student outcomes listed in Criterion 3 are addressed by this course:
       (1), (2), (3), (4), (6), (7)

7. Brief list of topics covered:

- Assembly language programming
- Interrupts and I/O
- Data conversion (analog to digital and digital to analog)
- Managing interrupts via concurrency: concurrency model, threads, synchronization
- Real-time constraints and scheduling

1. Course number and name: EENG 481 Advanced ABET Projects

2. Credits and contact hours: 3.0 credits, 4.5 hours/week

3. Instructor's name: Roman Kuc

4. Textbooks (title, author, publisher, year). Suggested and used for professional content.
   - Design for Electrical and Computer Engineers, by Ford & Coulston, McGraw-Hill, 2007.
   - The Engineering Capstone Course: Fundamentals for Students and Instructors, by H.F. Hoffman, Springer, 2014.

   a. Supplemental materials: On-line material including sensor data processing examples, current data sheets.

5. Specific course information:
   a. Brief description of the content of the course (catalog description):

      Study of the process of designing an electrical device that meets performance specifications, including project initiation and management, part specification, teamwork, design evolution according to real-world constraints, testing, ethics, and communication skills. Design project consists of electronic sensor, computer hardware, and signal analysis components developed by multidisciplinary teams.

   b. Prerequisites or co-requisites for course: EENG 310, 320, 325, 348.

   c. Prerequisite, required, or elective course: Required

6. Specific goals for the course

   a. Specific outcomes of instruction:

      The course is an electrical system design and development course where teams of nominally 4 students apply and demonstrate a broad and detailed knowledge of engineering fundamentals to design, construct and test a functioning prototype engineering system.

   b. Student outcomes listed in Criterion 3 that are addressed by this course:
      (1), (2), (3), (4), (5), (6), (7)

7. Brief list of topics to be covered:

Design as a process (conceptual, preliminary and detailed design phases), developing problem statements, establishing specifications, idea generation, project management, decision-making techniques, engineering standards, concept selection, prototype development, material/component selection, design for manufacturing, design for assembly, modelling/analysis, engineering experimentation, hazard analysis, safety considerations, engineering ethics, professional responsibility, patent process, engineering communications (including report writing, electronic archiving and project presentations), and product evaluation.

Appendix B – Faculty Vitae

Contents:

SEAS Dean Jeffrey Brock

EE Chair Leandros Tassiulas

DUS Mark Reed

EE Faculty:

Jung Han
Wenjun Hu
Amin Karbasi
Roman Kuc
T.P. Ma
Rajit Manohar
Steve Morse
Kumpati Narendra
Priyadarshini Panda
Jakub Szefer
Hong Tang
Rimas Vaisnys
Fengnian Xia

1. Name and Academic Rank: Jeffrey F. Brock
Dean, School of Engineering & Applied Science

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Mathematics	UC Berkeley	1997.
B.A.	Mathematics	Yale	1992.

3. Academic experience with institution rank and title:

Yale University
- Zhao and Ji Professor of Mathematics, 2019-present.
- Dean, School of Engineering & Applied Science, 2019-present,\
- *Dean of Science*, *Faculty of Arts & Sciences*, January 2019-present.
- *Professor*, Department of Mathematics, 2018-present.

Brown University
- *Director*, Data Science Initiative, 2016-2018.
- *Chair*, Department of Mathematics, 2013-2017.
- *Professor*, Department of Mathematics, 2007-2018.
- *Associate Professor* (with tenure), Department of Mathematics, 2003-2007.
- *Deputy Director*, ICERM, 2010-2013. *Associate Director*, 2013-2017.

University of Chicago
- *Assistant Professor*, Department of Mathematics, 2000-2003.

Stanford University
- *Szegö Assistant Professor*, Department of Mathematics, 1997-2000.

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Amer. Math. Society

7. Honors and awards:
- Elected Fellow, American Mathematical Society, 2017.
- John Simon Guggenheim Fellow, 2008.
- Donald D. Harrington Faculty Fellow, University of Texas at Austin 2003-2004.
- NSF Postdoctoral Fellow, Stanford University, 1997-2000.
- Alfred P. Sloan Doctoral Dissertation Fellow, U.C. Berkeley, 1996-1997.
- Outstanding Graduate Student Instructor Award, U.C. Berkeley, 1996.
- NSF Graduate Fellow, U.C. Berkeley, 1993-1996.
- Stanley and DeForest Mathematics Prizes, Yale University, 1991 and 1992.

8. Service activities:
- Physical Sciences and Engineering Advisory Committee, Yale. 2018-present.
- Diversity Committee, Brown Mathematics Department, 2017-2018.
- Organizer, Summer@ICERM Undergraduate Research Program, ICERM, 2017.
- Scientific Advisory Board, ICERM, 2017-present.
- Committee on Committees, American Mathematical Society, 2017-2018.
- Steering Committee, Brown University Data Science Initiative, 2015.
- Co-Chair, Search Committee, ICERM Director, 2014-2015.

- Chair, Department of Mathematics, 2013-2017.

9. Most important publications and/or presentations (within 5 years):
   - Limit sets of Weil-Petersson geodesics with nonminimal ending laminations. (With Christopher Leininger, Babak Modami, and Kasra Rafi). To appear, Journal of Topology and Analysis.
   - Correction to "On the density of geometrically finite Kleinian groups." (With Ken Bromberg). Acta Math., 219 (2017), pp. 17-19.
   - Local topology in deformation spaces of hyperbolic 3-manifolds II. (With Ken Bromberg, Richard Canary, Cyril Lecuire, and Yair Minsky). To appear, Groups, Geometry, and Dynamics.
   - Schwarzian derivatives, projective structures, and the Weil-Petersson gradient flow for renormalized volume. (With Martin Bridgeman and Ken Bromberg). To appear, *Duke Math. J.*
   - Machine learning algorithm for automatic detection of CT-identifiable hyperdense lesions associated with traumatic brain injury. Krishna N. Keshavamurthy ; Owen P. Leary ; Lisa H. Merck ; Benjamin Kimia ; Scott Collins ; David W. Wright ; Jason W. Allen ; Jeffrey F. Brock ; Derek Merck. Proc. SPIE 10134, Medical Imaging 2017: Computer-Aided Diagnosis, 101342G (March 23, 2017).
   - Limit sets of Weil-Petersson geodesics. (With Christopher Leininger, Babak Modami, and Kasra Rafi). IMRN.
   - Windows, cores, and skinning maps. (With Ken Bromberg, Dick Canary, and Yair Minsky). To appear, Annales scientifiques de l'ENS.
   - Limit sets of Teichmüller geodesics with minimal nonuniquely ergodic vertical foliation, II. (With Chris Leininger, Babak Modami, and Kasra Rafi). Crelle's Journal.
   - Norms on the cohomology of hyperbolic 3-manifolds. (With Nathan Dunfield). Invent. Math., 210, 2, (2017) pp. 531-558.
   - Geometric inflexibility of hyperbolic cone-manifolds. (With Ken Bromberg). In "Hyperbolic geometry and geometric group theory," Adv. Stud. Pure. Math 73, (2017), pp. 47-64.
   - Inflexibility, Weil-Petersson distance, and volumes of fibered 3-manifolds. (With Ken Bromberg). Math. Res. Lett. 23 (2016) pp. 649-674.

10. Professional development activities:
    - *Editorial board, Journal of Topology.* 2018 – present.
    - *Seminars:* Caltech, Columbia, CUNY, GA Tech, Harvard, Princeton, Stony Brook, Stanford, U.C. Berkeley, U.C. Davis, U.C. Santa Barbara,U. Chicago, U.I.C., U. Michigan, U. Maryland, USC, U. Texas, Yale.

1. Name and Academic Rank: Leandros Tassiulas
Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	University of Maryland	1991.
M.S.	Electrical Engineering	University of Maryland	1989.
B.S.	Electrical Engineering	Aristotelian University Thessaloniki	1987.

3. Academic experience with institution rank and title:

- Chair: Electrical Engineering Department, Yale University, July 2016-present.
- Professor: John C. Malone Professor, Yale University, July 2014-present.
- Professor: Computer Science, Yale University, 2015-present
- Professor: Computer and Telecommunications Engineering, University of Thessaly, 2002-2014
- Professor CS, University of Ioannina, 1999-2002

4. Non-academic experience:

- Associate Director: Informatics and Telematics Institute, Center for Research and Technology Hellas, 2009-2013
- Research Scientist: Institute for Systems Research, University of Maryland, 1995- 2005
- Senior Member of Technical Staff: NASA *Center for Satellite and Hybrid Communication Networks*, University of Maryland, College Park, MD July 1995- 2005
- Member of Technical Staff: IBM TJ Watson Research Center, 2002
- Member of Technical Staff: NY *Center for Advanced Technology in Telecommunications (CATT)* Brooklyn Polytechnic University 1991-1995.

5. Certifications or professional registrations: Technical Chamber of Greece

6. Current membership in professional organizations: IEEE, ACM

7. Honors and awards:

- Fellow of IEEE, 2007.
- ACM SIGMETRICS Achievement Award, 2020.
- IEEE International Conf, Computer Communications INFOCOM Best Paper Award, 2017.
- ACM International Symp. Mobile AdHoc Networking and Computing, Best Paper Award, 2016.
- IEEE Koji Kobayashi Computer and Communications Award, 2016.
- Distinguished Alumni Award, ECE, University of Maryland, College Park, 2015.

8. Service activities:

- Editor for the IEEE/ACM Transactions on Networking.
- Associate Editor for Communication Networks for the IEEE Transactions on Information Theory.

9. Most important publications and/or presentations (within 5 years):

- Green video delivery in LTE-based heterogeneous cellular networks. A Galanopoulos, G Iosifidis, Argyriou, L Tassiulas. IEEE 16th International Symposium on A World of Wireless, Mobile, 2015.
- Exploiting caching and multicast for 5G wireless networks. K Poularakis, G Iosifidis, V Sourlas, L Tassiulas. IEEE Transactions on Wireless Communications 15 (4), 2995-3007, 2016.
- Video delivery in dense 5G cellular networks. A Argyriou, K Poularakis, G Iosifidis, L Tassiulas. IEEE Network 31 (4), 28-34, 2017.
- Efficient and fair collaborative mobile internet access. G Iosifidis, L Gao, J Huang, L Tassiulas. IEEE/ACM Transactions on Networking 25 (3), 1386-1400, 2017.
- Throughput-optimal broadcast in wireless networks with dynamic topology. A Sinha, L Tassiulas, E Modiano. IEEE Transactions on Mobile Computing 18 (5), 1203-1216, 2018.
- Flexible SDN control in tactical ad hoc networks. K Poularakis, Q Qin, EM Nahum, M Rio, L Tassiulas. Ad Hoc Networks 85, 71-80, 2019.
- Matching theory application for efficient allocation of indivisible testbed resources. D Stavropoulos, V Miliotis, T Korakis, L Tassiulas. NOMS 2020-2020 IEEE/IFIP Network Operations and Management Symposium, 1-7, 2020.

10. Professional development activities:

- Expert witness in patent litigation.
- Expert evaluator and reviewer for the European Commission.

1. Name and Academic Rank: Mark A. Reed
Professor of Electrical Engineering and Applied Physics

2. Degrees with disciplines, institutions, and dates:

B.S.	Physics	Syracuse University	1977.
M.S.	Physics	Syracuse University	1979.
Ph.D.	Physics	Syracuse University	1983.

3. Academic experience with institution rank and title:
- Professor of Electrical Engineering and Applied Physics, Yale, July 1990 – present.
- Director of Undergraduate Studies, EE, Yale, 2010-2011, 2012-2013, 2015-present
- Assoc. Director, Yale Institute for Nanoscience and Quantum Engineering, 2007-15
- Chairman of Electrical Engineering, Yale University, 1995 – 2001

4. Non-academic experience
- Central Research Laboratories, Texas Instruments.
- Senior Member of the Technical Staff, 1983 – 1990.

5. Certifications or professional registrations: none

6. Current membership in professional organizations: APS; Connecticut Academy of Science and Engineering

7. Honors and awards:
- IEEE Fellow, 2009
- APS Fellow, 2003
- Finalist, World Technology Award (2010)
- IEEE Pioneer Award in Nanotechnology (2007)
- Fellow, Canadian Institute for Advanced Research (2006)
- YSEA Award for Advancement of Basic and Applied Science (2002)
- Fujitsu ISCS Quantum Device Award (2001)
- Syracuse University Distinguished Alumni Award (2000);
- Harold Hodgkinson Professor of Engineering and Applied Science, Yale U. (1999)
- DARPA ULTRA Most Significant Technical Achievement Award (1997)
- Kilby Young Innovator Award (1994)
- Fortune Magazine's 12 most promising young scientists (1990)

8. Service activities:
- Editor-in-Chief, Nanotechnology (2009-2019)
- Editor-in-Chief, Nano Futures (2016-present)
- Editorial board. IEEE Trans.Electron Devices, Proc. IEEE, Superlattices and Microstructures, Supermolecular Science and Technology, Small; Encyclopedia of Nanoscience and Nanotechnology.
- <u>Conference Chair:</u> Gordon Conference, Nanostructure Fabrication (2012), Vice-Chairman (2010), 27th International Symposium on Compound Semiconductors (ISCS) (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).
- <u>Program Chair:</u> 24th International Symposium on Compound Semiconductors (ISCS) (1997), <u>Publications Chair</u>, NANOMES 1996.

- Program committees: IEEE SISC (2018-), IEDM (2004-2006), AHW (1998, 1996, Other: Numerous NSF, DARPA, ONR, and government workshops. PCAST member, ITRS advisor. Scientific Advisory Boards: Sandia/LANL Center for Integrated Nanotechnologies, Penn NSF Nano/Bio Interface Center, Univ. of Copenhagen.

9. Most important publications and presentations from the past five years

- H. Song, T. Lee, and M.A. Reed, "Inelastic electron tunneling spectroscopy of molecular transport junctions", Jour. Korean Phys. Soc. 64, 1539 (2014).
- 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, 5315 (2014).
- S.X. Li, W. Guan, B. Weiner, and M.A. Reed, "Direct observation of charge inversion in divalent nanofluidic devices", Nano Lett., 15, 5046 (2015).
- 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 2017 89 (21), 11325-11331.
- 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, no. eaau4238, 22 Feb 2019.
- "Molecular Transistors, 7th International Conference on Molecular Electronics (ElecMol 2014), Strasbourg, France, 28 August 2014 (Plenary talk).
- "More Than Moore - When Electronics Drives Off The Roadmap, Kay Malmstrom Lecture in Physics, Hamline University.
- "Nanobioelectronic Systems", Quindao Symposium,18 June 2016 (Plenary talk).

10. Briefly list the most recent 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: Jung Han
Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

BS	Electrical Engineering	National Taiwan University	1986.
MS	Electrical Engineering	Purdue University	1990.
Ph.D.	Electrical Engineering	Purdue University	1992.

3. Academic experience with institution rank and title:

- 2015 - Present William A Norton Professor in Technological Innovation, Yale University
- 2010 - 2016 Chairman, Department of Electrical Engineering, Yale University
- 2005 - 2015 Professor of Electrical Engineering, Yale University
- 2001 - 2005 Associate Professor of Electrical Engineering, Yale University
- 1994 - 1996 Principal Research Scientist, Purdue University
- 1992 - 1994 Visiting Assistant Professor, Purdue University

4. Non-academic experience:
- 1996 - 2000 Senior Member of Technical Staff, Sandia National Laboratories

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: IEEE, OSA Connecticut Academy of Science and Engineering.

7. Honors and award

- Electronic and Photonic Division Award, The Electrochemical Society (ECS) (2019)
- Fellow, Optical Society of America (OSA) (2016)
- Fellow, Institutes of Electrical and Electronic Engineers (IEEE) (2013)
- Member, Connecticut Academy of Science and Engineering (CASE) (2012)
- Fellow, Institute of Physics (IoP), London (2011)
- Material Research Society Symposium Best Paper Ribbon Award (2005)
- R&D Magazine R&D100 Award "Cantilever Epitaxy of GaN for Defect Reduction" (2004)

8. Service activities:
- Director of Graduate Studies, Department of Electrical Engineering (2008-2010)
- Chairman, Department of Electrical Engineering (2010-2016)
- Dean's Executive Committee, School of Engineering and Applied Sciences (2010-2016)
- Advancement Committee of Engineering, School of Engineering and Applied Sciences (2010-2018)
- Advisory Committee, Energy Science Institute (2016-2018)
- Yale SEAS Dean Search Committee (2018-2019)
- Search Committee of Junior Faculty, Dept. of Electrical Engineering, Yale University, 2019.

9. Most important publications and/or presentations (within 5 years):

- K. Xiong, S. -H. Park, J. Song, G. Yuan, D. Chen, B. Leung, and J. Han. Single crystal gallium nitride nanomembrane photoconductor and field effect transistor. *Advanced Functional Materials* 2014, *24*, 6503.
- Conductivity based selective etch for GaN devices and applications thereof, J Han, Q Sun, Y Zhang – U.S. Patent 9,206,524 (December 8, 2015).
- Lateral electrochemical etching of III-nitride materials for microfabrication, U.S. Patent 9,583,353 (Feb 28, 2017)
- Large area, laterally-grown epitaxial semiconductor layers, US Patent 9,711,352 (July 18,2017)
- Nitrogen-polar Semipolar and gallium-polar semipolar GaN layers and devices on sapphire substrates, US Patent 9,978,589 (May 22, 2018)
- Method for obtaining planar semipolar gallium nitride surfaces US Patent 9,978,845 (May 22, 2018)
- Heterogeneous material integration through guided lateral growth, J. Han, US Patent 10,435,812 (Oct 09, 2019)
- Conductivity based selective etch for GaN devices and applications thereof, J Han, Q Sun, Y Zhang – U.S. Patent 10,458,038 (October 29, 2019).

10. Professional development activities:

- Program Committee, International Workshop on Nitride Semiconductors (IWN-2018), Kanazawa, Japan, November 2018.
- Guest Editor, Special Issue "Group III-V Nitride Semiconductor Microcavities and Microemitters" in Applied Sciences, 2019
- Co-chair, SPIE Photonics West, GaN Materials and Devices XIV, San Franscisco, February, 2019
- Program Committee, International Conference on Nitride Semiconductors (ICNS-13), Seattle, WA July 2019.
- Program Committee, 19th International Conference on Crystal Growth and Epitaxy (ICCGE-19) / 19th US Biennial Workshop on Organometallic Vapor Phase Epitaxy (OMVPE-19), Keystone, CO, July 2019.
- Co-chair, Program Committee, SPIE Photonics West, GaN Materials and Devices XV, San Franscisco, February, 2020
- International Advisory Committee, ICMOVPE XX, Stuttgart, Germany, June 14 to 19, 2020
- International Advisory Committee, 8th International Symposium on Growth of III-Nitrides (ISGN-8), San Diego, June 2020.

1. Name and Academic Rank: Amin Karbasi
Associate Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	EPFL	2012.
M.A.	Electrical Engineering	EPFL	2007.
B.S.	Electrical Engineering	EPFL	2004.

3. Academic experience with institution rank and title:

- Associate Professor of Electrical Engineering, 2020 – present.
- Assistant Professor of Electrical Engineering, 2015 – 2020.

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: IEEE, ACM

7. Honors and awards:

- NSF CAREER Award 2019
- ONR Young Investigator Award 2019
- Amazon Research Award 2018
- AFOSR Young Investigator Award 2018
- MICCAI Young Scientist Award 2017 for the paper "A Submodular Approach to Create Individualized Parcellations of Human Brain"
- Microsoft Azure Research Award 2017
- Grainger Award 2017 from National Academy of Engineering for Advancement of Interdisciplinary Research
- Simons Research Fellowship 2017 for "Foundations of Machine Learning"
- DARPA Young Faculty Award 2016
- Google Faculty Research Award 2016
- AISTATS Best Student Paper Award 2015 for the paper "Tradeoffs for Space, Time, Data and Risk in Unsupervised Learning"
- IEEE Data Storage Best Student Paper Award 2013 for the paper "Noise-Enhanced Associative Memories"
- Patrick Denantes Memorial Prize 2013 for the best Ph.D. thesis in the school of computer and communication sciences at EPFL

8. Service activities:

- Paper reviewer in the areas of Learning theory, large-scale networks, optimum information processing, high dimensional statistics, information theory, graphical models.

9. Most important publications and/or presentations (within 5 years):

- Mehraveh Salehi, Amin Karbasi, Daniel S. Barron, Dustin Scheinost, R. Todd Constable: Individualized functional networks reconfigure with cognitive state. NeuroImage 206 (2020)
- Mehraveh Salehi, Abigail S. Greene, Amin Karbasi, Xilin Shen, Dustin Scheinost, R. Todd Constable: There is no single functional atlas even for a single individual: Functional parcel definitions change with task. NeuroImage 208: 116366 (2020)

10. Professional development activities: N/A

1. Name and Academic Rank: Roman Kuc
Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	Columbia University	1977
M.S.	Electrical Engineering	Columbia University	1970
B.S.	Electrical Engineering	Illinois Institute of Technology	1968

3. Academic experience with institution rank and title:

- Professor of Electrical Engineering, Yale SEAS (ENAS), 1994-present
- Associate Dean, Yale SEAS (ENAS), 2000-2012
- Tenured Associate Professor of Electrical Engineering., Yale ENAS, 1987-1994
- Associate Professor of Electrical Engineering., Yale ENAS, 1983-1987
- Assistant Professor of Electrical Engineering., Yale ENAS, 1979-1983

4. Non-academic experience:

- Member of Technical Staff. Bell Labs, 1968-1975.

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Senior Member, IEEE, Member, Acoustical Society of America, Connecticut Academy of Science and Engineering

7. Honors and awards:

- Honorary Doctorate, Glushkov Institute of Cybernetics, Kyiv, Ukraine, 2013.
- Award for Excellence in Physical Sciences and Mathematics, for Springer Handbook of Robotics, by Professional & Scholarly Division, Association of American Publishers, Inc., 2008.
- Member, Connecticut Academy of Science and Engineering, 2004.
- Fellow, Shevchenko Scientific Society, 2001.
- Grand Order of the Golden Bulldog, Yale University, 1999.
- Academician (Honorary), Academy of Sciences of Ukraine, Kyiv, Ukraine, 1998.
- Sheffield Distinguished Teaching Award, Yale University, 1998.
- Master of Arts, *privatim*, Yale University, 1995.
- IEEE Acoustics, Speech and Signal Processing Society Paper Award, 1983.

8. Service activities:

- IEEE, Member, Multidimensional Signal Processing Technical Committee. 1984-1990.
- IEEE, Liaison, Steering Committee, Transactions on Medical Imaging.1984-1990.
- IEEE, ICASSP'88, Program Committee, Exhibits Chairman. 1988.
- IEEE, Associate Editor, Trans. on Acoustics Speech and Signal Processing. 1984-1987.
- IEEE, Member, Speech Processing Technical Committee. 1984-1987.
- IEEE, Chairman, CT Chapter, Engineering in Medicine and Biology Society. 11980-1984.
- IEEE, Faculty Adviser, Yale Student Chapter. 1980-1990.
- New York Academy of Sciences: Chair, Instrumentation Section. 1981-1983

- New York Academy of Sciences: Vice-chair, Instrumentation Section. 1979-1981.
- American Scientist Magazine: Consulting Editor (Electrical Engineering). 1983-1990
- Tau Beta Pi: Faculty Adviser, CT-α Chapter 1990-2007.

9. Most important publications and/or presentations (within 5 years):

- R. Kuc and V. Kuc. Modeling human echolocation of near-range targets with an audible sonar. Journal of the Acoustical Society of America, 139(2), 581-587, 2016.
- R. Kuc and V. Kuc. Experimental audible sonar to model echolocation by the blind. Proc. Meetings on Acoustics 29, 1-10, 2017.
- R. Kuc. Comparing phase-sensitive and phase-insensitive echolocation target images using a monaural audible sonar. Journal of the Acoustical Society of America, 143(4), 2379-2386, 2018.
- R. Kuc. Forming maps of targets having multiple reflectors with a biomimetic audible sonar. Journal of the Acoustical Society of America, 143(5), 2632-2638, 2018.
- R. Kuc. Audible biomimetic sonar images for target analysis. Proc. Meetings on Acoustics 30, 1-10, 2018.
- R. Kuc. Generating cognitive maps using echo features from a biomimetic audible sonar. Journal of the Acoustical Society of America, Journal of the Acoustical Society of America, 145(4), 2084-2093, 2019.
- R. Kuc. Artificial neural network classification of surface reflectors and volume scatterers using sequential echoes acquired with a biomimetic audible sonar. Journal of the Acoustical Society of America, 147(4), 2357-2364, 2020.

10. Professional development activities:

- Expert Witness in electro-mechanical devices, digital systems and telecommunications.
- Review panel member for NSF, NIH, EU, ISTEG, & NSER Canada.
- Workshop participant for DARPA, National Academy of Sciences, and ABET.
- Taught online courses in Machine Learning.

1. Name Tso-Ping Ma
   Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

B.S.E.E.	National Taiwan University	1968
M.Ph.	Yale University	1971
Ph.D.	Yale University	1974

3. Academic experience with institution rank and title:
   - Raymond J. Wean Chair Professor of Electrical Engineering, 2002-present.
   - Chairman, Department of Electrical Engineering, 1991-95, 2000-2007.
   - Co-Director, Yale-Peking Center for Microelectronics and Nanotech, 2005-15.
   - Co-Director, Yale Center for Microelectronic Mat. & Structures, 1999-2010.
   - Assistant Professor, Associate Professor, Professor, Yale University, 1977-1985.

4. Non-academic experience:
   - Staff Engr, IBM Systems Products Div., East Fishkill, N.Y., 1974-77.
   - Co-Founder, Chairman, AUCMOS Corp, 2016 to present. (Part time).

5. Certifications or professional registrations: NA

6. Current membership in professional organizations: Academia Sinica, Foreign Member of Chinese Academy of Sciences, NAE, Sigma Xi, YSEA, ECS, MRS, APS.

7. Honors and awards:
   - Fellow, IEEE.
   - <u>Beacon Award</u>, Chinese American Professors Association in Connecticut 11/2, 2019
   - Chinese American Academic and Professional Society (CAAPS) <u>Distinguished Academic Achievement Award</u>, August 17, 2019
   - <u>Outstanding Science/Technology Achievement Award,</u> Chinese Association for Science and Technology, USA; October 12, 2018.
   - <u>Honorary Doctor's</u> degree, National Chiao-Tung University, Taiwan, ROC, 3/17/2016
   - <u>Distinguished Achievement Award</u>, Chinese Institute of Engineers – USA Greater New York Chapter, 10/17/2015
   - Yale Science & Engineering Association Award for <u>Advancement of Basic and Applied Science.</u> 5/1/2015
   - <u>Outstanding Alumnus</u> Award by National Taiwan University, November 2014
   - <u>Connecticut Medal of Technology</u> 2008
   - SIA (Semiconductor Industry Association) <u>University Researcher Award</u> 2006
   - IEEE (Institute of Electrical and Electronic Engineers) <u>Andrew S. Grove Award</u> 2005

8. Service activities:

- Advisory Board, Chinese-American Professors Association in Conn. 2017-present.
- Member, IEEE Andrew Grove Award Committee, 2006-2008.
- Member, Advisory Committee, National Cheng Kung University, 2008. .
- Member, University of Texas at Dallas Research Advisory Board, 2002-2010.
- Chair, Visiting Committee for ECE of National University of Singapore, 2002-2005.
- Member, ITRI Nanotechnology Advisory Committee, Taiwan, ROC, 2003-2007.
- President, New Haven Chapter of the Organization of Chinese Americans, 1988-90.

- President of New Haven Chapter of Sigma Xi, 1987-88.
- Co-Director, Yale-Peking Joint Center for Microelectronics and Nanotech, 2005-present.
- Co-Director, Yale Center for Microelectronic Mat. & Structures, 1999-2014.
- Chairman, Department of Electrical Engineering, 2000-2007.
- Member, Yale Engineering Dean's Search Committee, 01/2007-12/2007.
- Member, Yale University International Affairs Advisory Group, 2005-2014.
- Member, Yale President's Minority Advisory Council, 2004-2007.
- Member, University Steering Committee for NEASC Accreditation, 1998-99.
- Member, Yale Division IV Advisory Committee, 1996, 1998-2000.
- Chair, Member, Teaching and Leaning Committee of Yale College, 1994- 96.
- Member, Executive Committee, Yale College, 1987-89.

9. Most important publications and presentations from the past five years

- T.P. Ma, "Ferroelectric 1-T Memory Technology: A Great Opportunity for China to Take a Leadership Role", Plenary talk at the International Memory Summit, Wuhan, China, March 28, (2016).
- T.P. Ma, "From Stone Age to Nanoelectronics", Keynote Speech delivered at the CAPA) Chinese American Professors Association –CT, October 22 (2016).
- T.P. Ma, "Versatile Memory: A Software Configurable Memory Technology Based on Ferroelectric FETs", Plenary Talk at the 13th International Conference on Solid-State and Integrated Circuit Technology (ICSICT-2016, Hangzhou, China,) Oct. 25 - 28th, (2016).
- T.P. Ma, "Opportunities and Challenges of Beyond-Si CMOS Technologies Based on High Mobility Channels" Keynote Speech, presented at the First International Semiconductor Conference for Global Challenges ((ISCGC 2017), Nanjing, China, July 16-19, (2017).
- T.P. Ma, "Challenges and Opportunities for High-mobility Channel Transistors", Keynote Speech at IEEE EDSSC, Shenzhen, China, June 6 (2018).
- T.P. Ma, "The Moore's Law and Evolution of Semiconductor Microchips", Keynote Speech at the Chinese Association for Science and Technology, USA Annual Convention, Oct.12-14, (2018).
- T.P. Ma, " The Global Outlook of China's Microchip Industry", Keynote Speech delivered at the Yale US-China Forum, held in Beijing, June 1, 2019.
- T.P. Ma, "Current Outlook and Future Prospect of China's Integrated Circuits Industry", Keynote Address delivered at the "International Summit of Innovation and Development of New Generations of Integrated Circuits", Shenzhen, China, Oct. 26-7, 2019.

10. Professional development activities N/A

1. Name Rajit Manohar
Professor of Electrical Engineering and Computer Science

2. Degrees with disciplines, institutions, and dates:

B.S.	E&AS	Cal Tech	1994
M.S.	CS	Cal Tech	1995
Ph.D.	CS	Cal Tech	1998

3. Academic experience with institution rank and title:

2017-	Professor, EE and CS, Yale University, New Haven, CT.
2012-2016	Professor, Cornell NYC Tech, New York, NY.
2010-2016	Professor, ECE, Cornell University, Ithaca, NY.
2004-2010	Associate Professor, ECE, Cornell University, Ithaca, NY.
1998-2004	Assistant Professor, ECE, Cornell University, Ithaca, NY.
2010-2012	Associate Dean for Research and Graduate Studies, College of Engineering, Cornell University, Ithaca NY.
2012-2015	Associate Dean for Academic Affairs, Cornell NYC Tech, Cornell University, New York, NY.

4. Non-academic experience:

2004-2010 Founder and Chief Technology Officer, Achronix Semiconductor Corp. *Full time: 2005-2007; part-time 2007-2010.*

5. Certifications or professional registrations: NA
6. Current membership in professional organizations IEEE (Senior Member), ACM.
7. . Service activities
   - Steering Committee Member, IEEE ASYNC Symposum (2017-2012).
   - Associate Editor, IEEE Transactions on VLSI (2007-2009).
   - Program Chair, IEEE ASYNC Symposium (2005).
   - Program Committee member, IEEE ASYNC Symposium (2001—present).
   - Reviewer for many IEEE journals, including Proceedings of the IEEE, IEEE Transactions on Circuits and Systems, IEEE Journal of Solid-State Circuits, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems.

Internal (Yale)
- Physical Sciences & Engineering Area/Tenure Appointments Committee (2018-20).
- Instrumentation Steering Committee (2019-20).
- Center for Research Computing Steering Committee (2019-20).
- Export Control Advisory Board (2019-20).
- Science of Data Working Group (2019-20).
- EE Faculty search committee (2018-2019)
- Faculty of Arts and Science Senate (2017-19, 2020).
- Cooperative Research Committee (2017-20).

8. Honors and Awards.

Best paper finalist, IEEE ASYNC Symposium (2019, 2017, 2016, 2015, 2014, 2010, 2005).
TrueNorth chip inducted into the Computer History Museum (2016).

Inaugural Misha Mahowald Prize for Neuromorphic Engineering (2016).
IBM Research 2014 Pat Goldberg Math/CS/EE Best Paper Award (2016).
Best paper award, Computer Architecture Letters (2015).
R&D100 Award IT/Electrical (2015).
Best paper award, IEEE ASYNC Symposium (2013, 2012, 2010, 2006).
IEEE Fred Ellersick Award (2005).
MIT Technology Review TR35 (2005).
NSF CAREER Award (2000).

9. Major Publications.

- Rajit Manohar and Yoram Moses. Asynchronous Signalling Processes. *Proceedings of the IEEE International Symposium on Asynchronous Circuits and Systems (ASYNC)*, 2019.
- A. Neckar, S. Fok, B. Benjamin, T. C. Stewart, N. N. Oza, A. R. Voelker, C. Eliasmith, R. Manohar, and K. Boahen. Braindrop: A Mixed-Signal Neuromorphic Architecture with a Dynamical Systems-Based Programming Model. *Proceedings of the IEEE*, 107(1):144-164, 2019.
- Wenmian Hua and Rajit Manohar. Exact Timing Analysis for Asynchronous Systems. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems,* 37(1):203-216, 2018.
- Yu Chen, Xiaoyang Zhang, Yong Lian, Rajit Manohar, Yannis Tsividis. A Continuous-Time Digital IIR Filter with Signal-Derived Timing and Fully Agile Power Consumption. *IEEE Journal of Solid-State Circuits,* 53(2):418-430, 2018.
- Filipp Akopyan, Jun Sawada, Andrew Cassidy, Rodrigo Alvarez-Icaza, John Arthur, Paul Merolla, Nabil Imam, Yutaka Nakamura, Pallab Datta, Gi-Joon Nam, Brian Taba, Michael Beakes, Bernard Brezzo, Jente Kuang, Rajit Manohar, William Risk, Bryan Jackson, and Dharmendra Modha. TrueNorth: Design and Tool Flow of a 65mW 1 Million Neuron Programmable Neurosynaptic Chip. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems,* 34(10), 2015.

1. Name and Academic Rank: A. Stephen Morse
Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	Purdue University	1967
M.S.	Electrical Engineering	University of Arizona	1964
B.S.	Electrical Engineering	Cornell	1962

3. Academic experience with institution rank and title:
- Professor of Electrical Engineering, Yale SEAS (ENAS), 1974-present.
- Chair, Dept. of Electrical Engineering, 2007 – 2010,

4. Non-academic experience:
- Research Scientist, Office of Control Theory and Application, NASA Electronics Research Center, 1969-1970.
- Captain, U.S. Army, Assigned to the Office of Control Theory and Application, NASA/ERC, 1967-69.

5. Certifications or professional registrations: N/A

6. Membership in professional organizations: Fellow, IEEE. Member National Academy of Engineering.

7. Honors and awards:
- Recipient of the 1999 IEEE Technical Field Award for Control Systems.
- Member, Connecticut Academy of Science and Engineering, 2003Member, Connecticut Academy of Science and Engineering, 2004.
- Recipient of the 2013 American Automatic Control Council Bellman Heritage Award.
- IFAC Fellow, 2014.

8. Service activities:
- Associate Editor, IEEE Trans. Automatic Control.
- Past Director of the American Automatic Control Council for SIAM.
- Guest Editor, Special 1999 Issue of Automatica on Hybrid System.
- Past Chair, Axelby Award committee.
- Past Chair, selection committee for IEEE Technical Field Award for Control Systems.
- Past Member, Peer Committee 7, National Academy of Engineering.
- National Academies (National Research Council's) Panel on Information Science.

9. Most important publications and/or presentations (within 5 years):
- B. D. O. Anderson, Shaoshuai Mou, A. Stephen Morse, and Uwe Helmke. Decentralized gradient algorithm for solution of a linear equation. *Numerical Algebra, Control and Optimization*, pages 319–328, 2016.
- J. Liu, A. S. Morse, A. Nedic, and T. Basar. Exponential convergence of a distributed algorithm for solving linear algebraic equations. *Automatica*, pages 37–46, 2017.
- L. Wang and A. S. Morse. A distributed observer for an time-invariant linear system. *IEEE Transactions on Automatic Control*, 63(7):2123–2130, 2018.
- Y. Li, F. Liu, and A. S. Morse. The power allocation game on a networks: Balanced equilibrium. In *Proceedings of the 2018 American Control Conference*, pages 6525–6532, 2018.

- L. Wang, J. Liu, A. S. Morse, B. D. O. Anderson, and D. Fullmer. A generalized discrete-time altafini model. In *Proceedings of the 2018 European Control Conference*, pages 1435–1440, 2018.
- Y. Li, J. Yue, F. Liu, and A. S. Morse. The power allocation game on a network: Computation issue. In *Proceedings of the 7th IFAC Workshop on Distributed Estimation and Control in Networked Systems*, pages 272–276, 2018.
- D. Fullmer and A. S. Morse. A distributed algorithm for computing a common fixed point of a finite family of paracontractions. *IEEE Transactions on Automatic Control*, pages 2833–2843, 2018.
- Daniel Fullmer and A. S. Morse. Analysis of difficulty control in bitcoin and proof-of-work blockchains. In *Proceedings of the 2018 IEEE Conference on Decision and Control*, pages 5988–5992, 2018.
- L. Wang, J. Liu, and A. S. Morse. A distributed observer for a continuous-time linear system. In *Proceedings of the 2019 American Control Conference*, pages 86–89, 2019.
- F. Liu and A. S. Morse. A graphical characterization of structurally controllable linear systems with dependent parameters. *IEEE Transactions on Automatic Control*, pages 4484–4495, 2019.
- L. Wang, J. Liu, A. S. Morse, and B. D. O. Anderson. A distributed observer for a discrete-time linear system. In *Proceedings of the 2019 IEEE Conference on Decision and Control*, pages 367–372, 2019.

10. Professional development activities:

- Reviewer: JACC, IEEE Trans. Auto. Control, SIAM J. Control, IFAC, Automatica, Information and Control, Applied Math and Optimization, NSF, NRC, International J. Control, Transp. Science, System and Control Letter, AFOSR.
- External Thesis Examiner: University of Toronto, Lund Institute of Technology, University of Newcastle, McGill University, University of Hamburg, University of Nante, University of Waterloo.
- NSF Research Initiation Grant and PYI panels.
- Past member Editorial Board, European Journal of Control, Adaptive Control and Signal Processing.

1. Name and Academic Rank: Kumpati S. Narendra
Harold W. Cheel Professor of Electrical Engineering,

2. Degree with disciplines, institutions and dates:

BS	Engineering	University of Madras, India	1954
MS	Applied Physics	Harvard	1955
PhD	Applied Physics	Harvard	1959

3. Academic experience with institution rank and title:

1961-1965	Assistant Professor, Harvard University.
1965-1968	Associate Professor, Yale University.
1968-present	Professor, Yale University.
1984-1987	Chairman, Department of Electrical Engineering, Yale University.
1981-present	Director, Center for Systems Science, Yale University.
1995-1996	Director, Neuroengineering and Neuroscience Center, Yale University.
2003	Harold W. Cheel Professor of Electrical Engineering.

4. Non-academic experience:
Consultant: JPL (1994-96), Neural Applications Corp. (1994-99), Sandia National Laboratories (1996-99). Scientific Systems (2009-2010).
5. Certifications or professional registrations: N/A

6. Membership in professional organizations:
Member, Sigma Xi; Fellow IEEE, Fellow American Association for the Advancement of Science, Fellow IEE (UK), Member, Connecticut Academy of Science and Engineering,

7. Honors and Awards:
Life Fellow IEEE, Richard E. Bellman Control Heritage Award (American Automatic control Council), Pioneer Award, IEEE Computational Intelligence Society, Centenary Lecture: Indian Institute of Science.

8. Service activities:
Served on numerous national and international committees and is currently on the editorial board of several technical journals. Since 1979, has organized and hosted 16 workshops on Adaptive and Learning Systems at Yale University. The Sixteenth Yale Workshop was held in June 2013.

9. Most important publications and/or presentations (within 5 years):

a. K. S. Narendra and A. M. Annaswamy, *Stable Adaptive Systems*, Prentice-Hall. (Chosen for republication in 2005 by Dover.)
b. K.S. Narendra and M.A. L. Thathachar, *Learning Automata – An Introduction*, Prentice-Hall.
c. Currently working on the book "*Neural Networks for Adaptive Identification and Control*".

K. S. Narendra, R. Ortega and P. Dorato, Advances in Adaptive Control, IEEE Press, Piscataway, New Jersey 1991

10. Professional development activities:

1. Name and Academic Rank: Priyadarshini Panda
Assistant Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	Purdue University	2019
M.Sc.	Electrical Engineering	B.I.T.S, Pilani, India	2013
B.E.	Electrical Engineering	B.I.T.S	2013

3. Academic experience with institution rank and title:
- Assistant Professor of Electrical Engineering, 2019 – present.

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations:
- Member – IEEE, ACM.

7. Honors and awards:
- Winner of 2019 Amazon Research Award for conducting research on 'Adversarial Robustness in Deep Neural Networks'.
- Outstanding Poster Award in 2018 Center for Brain-Inspired Computing Annual Review for research on "Opportunities and Challenges with Liquid State Machines".
- Awarded Certificate of Recognition for being among Top-3 in the 2017 Intel Labs Intern Showcase.
- Awarded ECE Scholarship for 2015 Grace Hopper Conference sponsored by Apple Inc.

8. Service activities:
- Paper reviewer in the areas of neural networks, neuromorphic computing, hardware design, design automation, VLSI circuits and architecture.
- Served in Technical Program Committee for Embedded and VLSI Design Conference (VLSID 2020), Design Automation Conference (DAC 2020).
- Session Chair in Workshop on Bridging the Gap between Natural and Artificial Intelligence, DAC 2019.
- Organizer of Workshop on Neuromorphic Computing: Opportunities, Challenges and Perspectives, DAC 2020.

9. Most important publications and/or presentations (within 5 years):
- Kaushik Roy*, Akhilesh Jaiswal*, and Priyadarshini Panda**.** Towards Spike-based Machine Intelligence with Neuromorphic Computing**.** *Nature* 575.7784 (2019).

- Fan Zuo, Priyadarshini Panda, Michele Kotiuga, Jiarui Li, Mingu Kang, Claudio Mazzoli, Hua Zhou et al. Habituation based synaptic plasticity and organismic learning in a quantum perovskite**.** *Nature communications* 8, (2017).

- Priyadarshini Panda, Swagath Venkataramani, Abronil Sengupta, Anand Raghunathan, and Kaushik Roy. Energy-efficient object detection using semantic decomposition**.** *IEEE Transactions on Very Large Scale Integration (VLSI) Systems* (2018)

- Priyadarshini Panda, Indranil Chakraborty, and Kaushik Roy. Discretization based Solutions for Secure Machine Learning against Adversarial Attacks**.** *IEEE Access* (2019).

- Abhronil Sengupta, Priyadarshini Panda, Parami Wijesinghe, Yusung Kim, and Kaushik Roy. Magnetic tunnel junction mimics stochastic cortical spiking neurons**.** *Scientific reports* (2016).

- Deboleena Roy, Priyadarshini Panda, and Kaushik Roy. Tree-CNN: A hierarchical deep convolutional neural network for incremental learning**.** *Neural Networks* (2019).

- Chankyu Lee, Priyadarshini Panda, Gopalakrishnan Srinivasan, and Kaushik Roy. Training deep spiking convolutional neural networks with stdp-based unsupervised pre-training followed by supervised fine tuning**.** *Frontiers in Neuroscience,* 12:435 (2018).

10. Professional development activities: N/A

1. Name and Academic Rank: Jakub Szefer
Associate Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	Princeton	2013
M.A.	Electrical Engineering	Princeton	2009
B.S.	Electrical and Computer Engineering	University of Illinois at Urbana-Champaign	2006

3. Academic experience with institution rank and title:
- Associate Professor of Electrical Engineering, 2020 – present.
- Assistant Professor of Electrical Engineering, 2013 – 2020.

4. Non-academic experience:
- MIPS Technologies, Architecture Intern, Summer 2008
- MIPS Technologies, Architecture Intern, January-July 2007

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Member – IEEE, ACM

7. Honors and awards:
- IEEE Senior Member, 2019.
- National Science Foundation's Faculty Early Career Development Award (CAREER), 2017.
- Wu Prize for Excellence "awarded to engineering graduate students who have performed at the highest level as scholars and researchers," Princeton University, School of Engineering & Applied Science, 2012.
- Nominated and selected as department's representative for the IBM Ph.D. Fellowship and the Intel Ph.D., Fellowship, 2012.
- Outstanding Teaching Assistant Award, Princeton University, Dept. of Electrical Engineering, 2011.
- Outstanding Teaching Assistant Award, Princeton University, Dept. of Electrical Engineering, 2010.

8. Service activities:
Journal and Conference Reviewer: IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems (TCAD), IEEE Transactions on Reliability (TR), IEEE Computer Architecture Letters, IEEE Transactions on Computers (TC), IEEE Transactions on Information Forensics & Security (TIFS), IEEE Transactions on Emerging Topics in Computing (TETC), IBM Journal of Research and Development.

9. Most important publications and/or presentations (within 5 years):
- Book: Jakub Szefer, "Principles of Secure Processor Architecture Design", Morgan & Claypool Publishers, 2018.
- Wen Wang, Shanquan Tian, Bernhard Jungk, Nina Bindel, Patrick Longa, and Jakub Szefer, "Parameterized Hardware Accelerators for Lattice-Based Cryptography and Their Application to the HW/SW Co-Design of qTESLA", in Proceedings of the Conference on Cryptographic Hardware and Embedded Systems (CHES), 2020.
- Ilias Giechaskiel, Kasper Rasmussen, and Jakub Szefer, "CAPSULe: Cross-FPGA Covert-Channel Attacks through Power Supply Unit Leakage", in Proceedings of the IEEE Symposium on Security and Privacy (S&P), 2020.

- Wenjie Xiong, and Jakub Szefer, "Leaking Information Through Cache LRU States", in Proceedings of the International Symposium on High-Performance Computer Architecture (HPCA), 2020.
- Shuwen Deng, Wenjie Xiong, and Jakub Szefer, "Secure TLBs", Proceedings of the International Symposium on Computer Architecture (ISCA), 2019.
- Nikolay Matyunin, Jakub Szefer, and Stefan Katzenbeisser, "Zero-Permission Acoustic Cross-Device Tracking", in Proceedings of International Symposium on Hardware Oriented Security and Trust (HOST), 2018. (Best Student Paper Winner).
- Wen Wang, Jakub Szefer, and Ruben Niederhagen, "FPGA-based Key Generator for the Niederreiter Cryptosystem using Binary Goppa Codes" in Proceedings of the Conference on Cryptographic Hardware and Embedded Systems (CHES), 2017.
- André Schaller, Wenjie Xiong, Muhammad Umair Salee, Nikolaos A. Anagnostopoulos, Stefan Katzenbeisser, and Jakub Szefer, "Intrinsic Rowhammer PUFs: Leveraging the Rowhammer Effect for Improved Security" in Proceedings of the International Symposium on Hardware Oriented Security and Trust (HOST), 2017. (Best Student Paper Finalist)
- Wen Wang, Jakub Szefer, and Ruben Niederhagen. "Solving Large Systems of Linear Equations over GF(2) on FPGAs." In Proceedings of the International Conference on Reconfigurable Computing and FPGAs, ReConFig, 2016.
- Wenjie Xiong, Andre Schaller, Nikolaos A. Anagnostopoulos, Muhammad Umair Saleem, Sebastian Gabmeyer, Stefan Katzenbeisser, and Jakub Szefer. "Run-time Accessible DRAM PUFs in Commodity Devices." Proceedings of the Conference on Cryptographic Hardware and Embedded Systems, CHES, 2016.

10. Professional development activities: N/A

1. Name and Academic Rank: Hong Tang
Professor of Electrical Engineering & Applied Sciences

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Physics	Cal Tech	2002
M. Phil	Physics	University of Hong Kong	1997
B. S.	Physics	University of Science and Technology of China	1994

3. Academic experience with institution rank and title:
- Llewellyn West Jones Jr. Professor of Electrical Engineering, 2016-present.
- Professor of Electrical Engineering, 2015-present.
- Professor of Physics and Applied Physics, Yale University, 2015-present.
- Associate Professor of Electrical Engineering, Yale University (w tenure), 2011-present.
- Associate Professor of Electrical Engineering, Yale University (w/o tenure), 2010-2011.
- Assistant Professor of Mechanical Engineering, Yale University, 2006-2009.
- Assistant Professor of Electrical Engineering, Yale University, 2006-2010.
- Senior Research Scientist, California Institute of Technology, 2002-2003.
- Graduate Research Assistant, California Institute of Technology, 1998-2002.

4. Non-academic experience:
- Co-founder, Nanotechnica Corporation, Pasadena, CA, 2004-2005.

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: Elected Member, Connecticut Academic of Science and Engineering (CASE), 2013; Senior Member of IEEE (2006-), Optical Society of America (2003-), American Physical Society (1999-), Material Research Society (2012-), Senior member of Sigma Xi (2003-)

7. Honors and awards:
- Arthur Greer Memorial Award, 2010.
- Packard Fellowship in Science and Engineering, 2009.
- NSF CAREER Award, 2009.
- Yale Junior Faculty Fellowship, 2009.
- Invited participant of National Academy of Engineering Symposium, 2008.

8. Service activities:
- Chair, faculty search committee, Electrical Engineering, Yale University (2012, 2020).
- Committee member, Yale Quantum Material Initiate Workgroup (2019-present).
- Yale Engineering Dean's search committee (2017-2018).
- Physical Science & Engineering Advisor Committee and Tenure Appointments Committee (2016-2018).
- Yale Quantum Institute Advisory Committee (2014-present).
- Director of Graduate Studies, Electrical Engineering, Yale University (2010-present).
- Cleanroom executive committee (2008-present).
- Faculty search committee (for applied physics, 2011-2012).
- Silliman Lectureship selection committee, Yale University (2011-2012) .
- Pierson College freshmen advisor (2009-2016).

9. Most important publications and/or presentations (within 5 years):

- “Radiative cooling of a superconducting resonator”, M Xu, X Han, CL Zou, W Fu, Y Xu, C Zhong, L Jiang, HX Tang, arXiv preprint arXiv:1910.01203, Physical Review Letter, 124, 033602 (2020).
- “Broadband on-chip single-photon spectrometer”, R.S. Cheng, C. L. Zou, X. Guo, S. H. Wang, X. Han, H. X. Tang, Nature Communications 10, 1 (2019).
- “Phononic integrated circuitry and spin–orbit interaction of phonons”, W Fu, Z Shen, Y Xu, CL Zou, R Cheng, X Han, HX Tang, Nature communications 10, 2743 (2019).
- "High speed travelling wave single-photon detectors with near-unity quantum efficiency", W. H. P. Pernice, C. Schuck, O. Minaeva, M. Li, G.N. Goltsman, A.V. Sergienko, H. X. Tang, Nature Communications 3, 1325 (2012).
- “Beyond 100 THz-spanning ultraviolet frequency combs in a non-centrosymmetric crystalline waveguide”, X. W. Liu, A. W. Bruch, J. J. Lu, Z. Gong, J. Surya, L. Zhang, J. X. Wang, J. C. Yan, H. X. Tang, Nature Communications 10, 2971 (2019).
- “Spectro-temporal shaping of itinerant photons via distributed nanomechanics”, L. R. Fan, C. L. Zou, N. Zhu, H. X. Tang, Nature Photonics, doi.org/10.1038/s41566-019-0375-9 (2019).
- “Superconducting cavity electro-optics: a platform for coherent photon conversion between superconducting and photonic circuits”, Linran Fan, Chang-Ling Zou, Risheng Cheng, Xiang Guo, Xu Han, Zheng Gong, Sihao Wang, H. X. Tang, Science Advances 4, eaar4994 (2018).

10. Professional development activities:

- Associate editor, Focus issue on cavity optomagnoncis, New Journal of Physics, 2019- present.
- Non-local member of Hong Kong Research Grants Council, 2017-2018.
- Conference co-organizer, IEEE Summer Topical Meeting, San Juan, Puerto Rico, 2016-2017.
- NSF Panel on Midscale Instrumentation for Quantum materials, 2016.
- Guest editor, Journal of Photonics, 2015- present.
- CLEO Nanophotonics committee, 2013- present.

1. Name and Academic Rank: J. Rimas Vaisnys
Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:
Ph.D. Electrical Engineering UC Berkeley 1975

3. Academic experience with institution rank and title:
Professor of Electrical Engineering, Yale SEAS

4. Non-academic experience: N/A

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: IEEE.

7. Honors and awards: N/A

8. Service activities: Quorum member JBPO.

9. Most important publications and/or presentations:

- Dynamics of Gastrovascular Circulation in the Hydrozoan Podocorynecarnea: The One-Polyp Case , S. Dudgeon, A. Wagner, J. Rimas Vaisnys, L.W. Buss, 1999, *Biol. Bull.*, 196, 1-17.
- Approximate Analysis of a Piece-Wise Linear Population Model , J. Rimas Vaisnys, M. Tamosiunaite, 1997,*Information Technology and Control*, 4, 49.
- Analysis of Paedomorphosis using Allometric Characters: The Example of Reduncini Antelopes (Bovidae, Mammalia) , E.S. Vrba, J. Rimas Vaisnys, J.E. Gatesy, R. DeSalle, 1994, *Systematic Biology*, 43(1), 93-116.
- Temperature Stress Induces Dynamical Choas in a Cnidarian Gastrovascular System , L.W. Buss, J. Rimas Vaisnys, 1993, *Proc. Roy. Soc. Lond. B*, 252, 39-41.

10. Professional development activities: N/A.

1. Name and Academic Rank: Fengnian Xia
Associate Professor of Electrical Engineering

2. Degrees with disciplines, institutions, and dates:

Ph.D.	Electrical Engineering	Princeton University	2005
M.S.	Electrical Engineering	Princeton University	2001
B.E.	Electronics Engineering	Tsinghua University	1998

3. Academic experience with institution rank and title:
- Associate Professor of Electrical Engineering, Yale, 2016-present.
- Assistant Professor of Electrical Engineering, Yale, 2013-2016.

4. Non-academic experience:
- Postdoc, Engineer & Research Staff, IBM Research, 2005-2013.

5. Certifications or professional registrations: N/A

6. Current membership in professional organizations: N/A

7. Honors and awards:
- 2019: Presidential Early Career Award for Scientists and Engineers (PECASE) .
- 2017-2019: Highly Cited Researcher, Clarivate Analytics .
- 2016: National Science Foundation CAREER Award.
- 2015: Barton L. Weller Endowed Junior Professorship, Yale University.
- 2015: Office of Naval Research Young Investigator Program Awardee.
- 2012: IBM Corporate Award (the highest award that IBM grants to its employees).
- 2011: TR35, MIT Technology Review's Top Young Innovator under 35.

8. Service activities:
- *Journal Review*: Science; Science Advances; Nature; Nature Nanotechnology; Nature Physics; Nature Materials; Nature Photonics; Nature Communications; ACS Nano; Nano Letters; Journal of American Chemical Society; Small; Nanoscale; PNAS; Applied Physics Letters; Physical Review Letters; Physical Review B; Physical Review X; AIP Advance; Advanced Materials; Optics Letters; Optics Express; Proceedings of the IEEE; IEEE Photonics Technology Letters; IEEE Journal of Lightwave Technology; IEEE Journal of Quantum Electronics; IEEE Transactions on Electronic Device; IEEE Electronic Device Letters, etc.
- *Grant Review:* National Science Foundation; Department of Energy; Air Force Office of Scientific Research; Army Research Office; German-Israel Foundation; German Research Foundation; Marie-Curie Actions; Israel Ministry of Science; Netherlands Organization for Scientific Research; ACS Petroleum Fund; European Commission Flagship Projects; European Research Council; Natural Sciences and Engineering Research Council of Canada; French National Research Agency; Singapore Ministry of Education; Hong Kong Research Grants Council; Multiple Private Foundations.

9. Most important publications and/or presentations (within 5 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 thin-film black phosphorus," *Science Advances* 6, eaay6134 (2020).

- 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, 7771-7779 (2019).
- 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, 99-119 (2019).
- 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, 306–317 (2019).
- Q. Guo, R. Yu, C. Li, S. Yuan, B. Deng, F. J. García de Abajo, and F. Xia, "Efficient Electrical Detection of Mid-infrared Graphene Plasmons at Room Temperature," *Nature Materials* 17, 986-992 (2018).
- R. Yu, Q. Guo, F. Xia, and F. J. García de Abajo, "Photothermal Engineering of Graphene Plasmons," *Physical Review Letters* 121, 057404 (2018).
- 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, 1672 (2017).
- M. Mariano, O. Mashtalir, F. Q. Antonio, W.-H. Ryu, B. Deng, F. Xia, Y. Gogotsib, and A. D. Taylor, "Solution-Processed titanium carbide MXene films examined as highly transparent conductors," *Nanoscale* 8, 16371–16378 (2016).
- F. Xia, "Flat talk," *Nature Photonics* 10, 205-206 (2016). (*Interview*)
- X. Ling, H. Wang, S. Huang, F. Xia, and M. S. Dresselhaus, "The renaissance of black phosphorus," *Proceedings of the National Academy of Sciences* 112, 4523-4530 (2015).
- X. Wang, A. M. Jones, K. L. Seyler, V. Tran, Y. Jia, H. Zhao, H. Wang, L. Yang, X. Xu, and F. Xia, "Highly anisotropic and robust excitons in monolayer black phosphorus," *Nature Nanotechnology* 10, 517-521 (2015).
- X. Wang, and F. Xia, "van der Waals heterostructures: Stacked 2D materials shed light," *Nature Materials* 14, 264-265 (2015). (News & Views)

10. Professional development activities:

- *Editorial Board:* Nano Research (Springer and Tsinghua University Press); Advanced Optical Materials (Wiley); 2D Materials (IOP).
- *Primary Guest Editor:* IEEE Journal of Selected Topics of Quantum Electronics.

Appendix C – Equipment

The EE laboratories are contained in the Linda and Glenn H. Greenberg Engineering Teaching Concourse (GETC), consisting of 8 labs suited for accommodating various student needs. Four of the labs are outfitted with Advanced and Basic electronics equipment and a fourth lab is configurable to support workstation-based EE lab instruction.

The Greenberg Engineering Teaching Concourse also includes an office area for the teaching support staff, with the staff readily available to assist students within the facility. The concourse also includes large and well-designed storage rooms for electronic supplies and additional equipment. These rooms provide space to prepare lab activities and set-ups that can then be moved into the instructional labs. The Electrical Engineering laboratories are well equipped and provide excellent support for laboratory instruction and design courses.

Advanced Electronics Lab Equipment: Twelve fully equipped workstations (each with a snorkel) are available for the advanced electrical engineering labs students. As shown in Figures C-1 and C-2, each workstation in the Advanced Lab 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 (type: 10KE, model number: 001FUS)
- KEITHLEY 2231A-30-3 Triple Channel DC Power Supply
- KEYSIGHT U1233A True RMS Multimeter
- KEITHLEY 2450 Source Meter
- Agilent 33120A 15MHz Function/ Arbitrary Waveform Generator
- HEWLETT PACKARD 33120A 15MHz Function/ Arbitrary Waveform Generator
- Tektronix AFG1022 25MHz 125MS/s Arbitrary Function Generator

Figure C-1: EE Lab Advanced Electronics Workstations.

Figure C-2: View of the typical student workstation in the Advanced Electronics Lab.

Advanced Electronics Lab Equipment: Twenty-four fully equipped workstations in two labs are geared toward this level of instruction (illustrated in Figures C-3 and C-4).

Figure C-3: Basic electronics instruction areas within the Greenberg Engineering Teaching Concourse.

Figure C-4: Basic electronics workstations within 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

All the computer workstations are 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
- MATHLAB R2017a
- Microsoft suite
- National Instruments Software
- Tektronix OpenChoice
- SOLIDWORKS (Electrical, Composer)

Additional Greenberg Engineering Teaching Concourse Electronics Equipment: Additional equipment is available at the Greenberg Teaching Concourse for the construction and modification of PCB and SMT boards. The LPKF ProtoMat S64 shown in Fig 5 is available at the electrical engineering labs for PCB design and fabrication. This unit is a state-of-the-art circuit board plotter for in-house rapid PCB prototyping. It allows for producing structures up to 100um.

Figure C-5: LPKF ProtoMat PCB Plotter.

A ProtoPlace S Pick and Place Machine is also available in the concourse. This machine is a semi-automatic system for assembling SMT boards by pneumatically placing components in the correct location. The user can determine the placing through the LCD camera of the system.

C-6: The ProtoPlace S used for assembling SMT boards.

The **Center for Engineering Innovation and Design (CEID)** contains a variety of tools and equipment accessible to students in the CEID's Electronics Station, Wet Lab, Studio, and Machine Shop and Wood Shop. Of most relevant to EE students are the Electronic Equipment Stations.

The two CEID Electronic Equipment Stations (Figure C-9) are outfitted with equipment that matches the equipment used in the Greenberg Engineering Teaching Concourse. 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.
Each CEID Electronic Equipment Station is outfitted with:

- 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.)

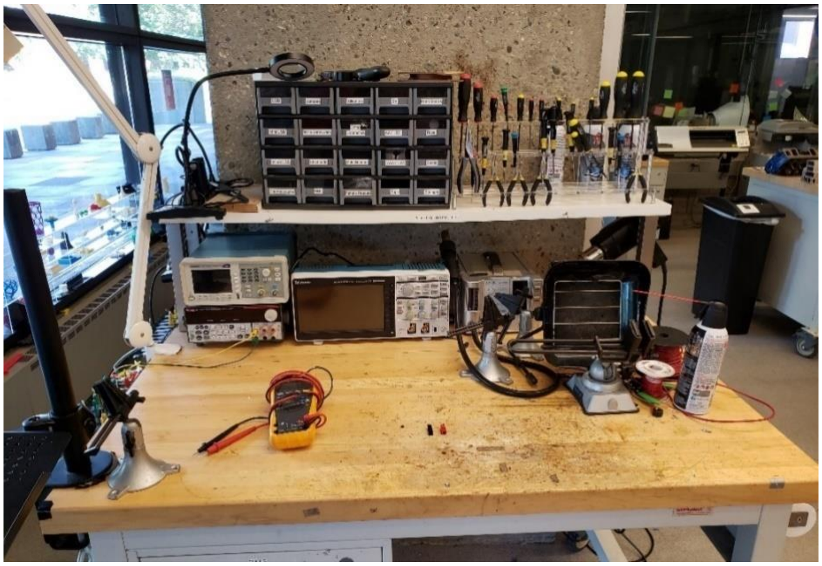


Figure C-9: Oscilloscope, soldering kit, multimeters, power supply, and function generator at one of the CEID electronics stations.

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:

- 2012: Interim Visit

2. *Type of Control*

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 School of Engineering & Applied Science Department Chairs report to the Dean of the School of Engineering & Applied Science on administrative and educational matters. Jeffrey Brock serves as the Dean of the School of Engineering & Applied Science. He also serves as the Dean of Science. Dean Brock was appointed Dean of Engineering and Applied Science in August 2019. Organizational diagrams for the School of Engineering and Applied Science and Yale University is presented in Figure D.1.

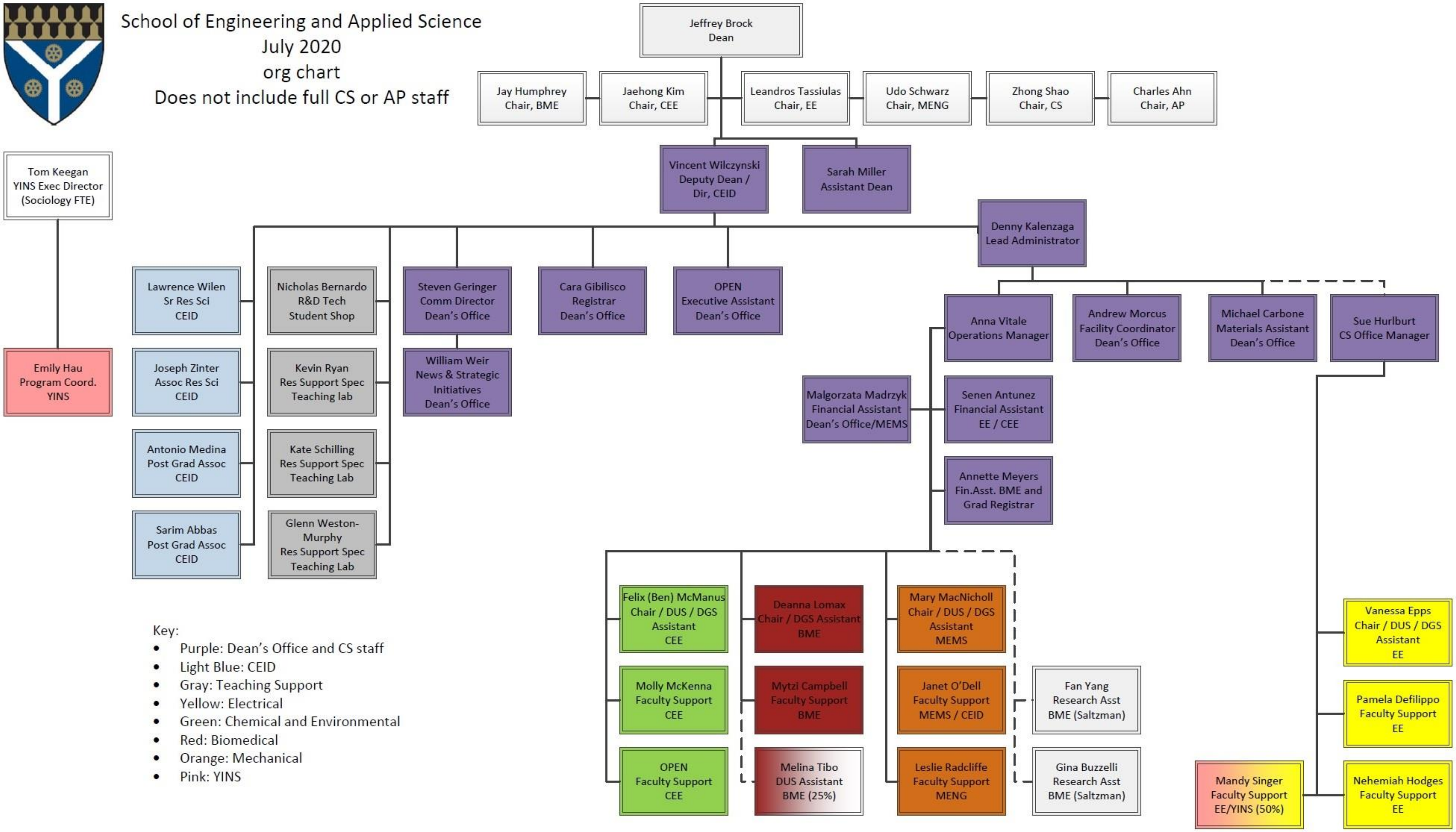


Figure D.1: Yale School of Engineering & Applied Science Organizational Diagram

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 Supporting 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 Mechanical Engineering	Udo Schwarz	Chair

5. Non-academic Support Units

Non-Academic Supporting Unit	Responsible Name	Title
Yale College	Marvin Chun	Dean of Yale College
Engineering & Applied Science Librarian	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
Center for Innovative Thinking at Yale	Claire Leinweber	Executive Director

6. Credit Unit

One semester course normally represents three class hours (50 minutes) or three laboratory hours per week. One academic year normally represents at least 14 weeks of classes, exclusive of final examinations.

7. Tables

Enrollment and Personnel details are presented on the following tables.

Table D-1. Program Enrollment and Degree Data

Electrical 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			21	17		38	55	N/A	6/17	1	8
		PT							1				
1 year prior to current year	2018-2019	FT			16	22		38	52	N/A	4/22	0	4
		PT							1				
2 years prior to current year	2017-2018	FT			22	18		40	52	N/A	8/18	2	10
		PT							1				
3 years prior to current year	2016-2017	FT			18	18		36	52	N/A	6/18	0	4
		PT							2				
4 years prior to current year	2015-2016	FT			18	15		33	46	N/A	4/15	0	4
		PT							0				

Give 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 reflects (BSEE) / (total of (BSEE, BSES(EE), BAES(EE), BSEE/CS)

Table D-2. Personnel

Department of Electrical Engineering

Year[1]: 2019 - 2020

	HEAD COUNT		FTE[2]
	FT	PT	
Administrative[2]	3*	-	3*
Faculty (tenure-track)[3]	15**	-	15**
Other Faculty (excluding student Assistants)	0	-	0
Student Teaching Assistants[4]	25	-	12.5
Technicians/Specialists	1	-	1
Office/Clerical Employees	3	-	3
Others[5]	-	-	-

Report data for the program being evaluated.

1. Data on this table should be 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 relieve allocated to these positions.
** Full-time faculty allocations were applied for the Chair, Director of Undergraduate Studies and Director of Graduate Studies, with teaching relieve allocated to these positions.

Signature Attesting to Compliance

By signing below, I attest to the following:

That Yale's Electrical 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**