EMBEDDING DESIGN THINKING IN A MULTIDISCIPLINARY ENGINEERING CURRICULUM

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Abstract

The 21st Century inherited complex challenges that require new methodologies and processes to solve. Engineering has a critical role to play in solving these problems, but our educational system needs to evolve in ways that require considerable organizational change inside established universities. Engineering embedded in a liberal arts education provides unique opportunities, especially when innovation education is integrated throughout the curriculum. The case of Harvard's School of Engineering and Applied Sciences curriculum development provides an example of a successful organizational transition toward multidisciplinary innovation education. Change was enabled primarily by a core group of faculty willing to eschew academic silos, and a trans-disciplinary structure that did not include specific departments. Established in 2007, SEAS (Harvard's newest school) has no departments, mostly interdisciplinary research, and a substantial portion of cross-disciplinary and system-level courses that are transforming undergraduate engineering education. In four years, in the area of multidisciplinary design, engineering, and entrepreneurship, SEAS has increased: its faculty by 144%; courses by 500% (and enrollment in these courses by non-engineering students by 142%); teaching lab space by 367%; and support staff by 400%. In addition, SEAS has created innovative teaching and learning assessment and implemented major extracurricular support programs.

Engineering in a Liberal Arts Context

The School of Engineering and Applied Sciences (SEAS) at Harvard is one of twelve degree-offering schools at Harvard University. It offers students a full undergraduate curriculum, as well as master's and PhD programs. Established in 2007, SEAS is the newest school in America's oldest university, and it is transforming undergraduate engineering education. The School has no departments; most research is interdisciplinary and the curriculum includes significant cross-disciplinary and system-level courses.

SEAS is embedded in a fundamentally liberal arts school. Unlike some programs in engineering and applied sciences, Harvard undergraduates who pursue the field are not admitted to the engineering school but rather are admitted to and remain students of Harvard College throughout their tenure. Students majoring in engineering are simultaneously immersed in the liberal arts environment, which provides a foundation for understanding the societal context for their technical problem solving. Moreover, SEAS wants to enable students from all other majors to learn how engineering and technology underpin many aspects of society and the world, and thus SEAS courses are open to all Harvard undergraduates. SEAS exposes all Harvard College students to the opportunity to learn the tenets of engineering – analysis, synthesis/integration, design, and building – and hence they gain greater appreciation for science and technology and become better prepared for the 21st century world in which technology is part of every sphere of life.

An understanding of changing technology is essential for devising solutions to the world's most complex problems. The Harvard SEAS curriculum design responds to this need, while also resonating with today's information-savvy college students, who well understand that the explosion of knowledge and new technology has transformed society. Interjecting innovation and entrepreneurial training into our curriculum requires that we place a focus on "organizational self-discovery… construct opportunities for interaction to develop new mental models… and connect the change process to individual and institutional identity" (Kezar 2001). While Henderson and Clark (1990) use their model to examine product innovation in established firms, we recognize similarities of their framework toward the "innovation" of the university as it relates to advancing engineering education to foster innovative and entrepreneurial-minded leadership.

Against this backdrop, within SEAS we propose that engineering will become essential core knowledge for every broadly educated person – and indispensable background for leaders. At the same time, engineers, scientists, and inventors who will help address the "grand challenges" of the future will need more than technical expertise. In addition to mastering sophisticated new tools and methods from the discipline of engineering, they will also need deep knowledge of societal context as well as critical thinking skills derived from broad exposure to the arts, humanities, and social sciences to effect maximum impact for the common good. Systemic problems like climate change, global demands for energy, cyber-security, clean water delivery, modern infrastructure, and health care for a growing population are not solvable by a single discipline. These challenges are unprecedented in their complexity and require new approaches and methodologies.

Engineering has a critical role to play in supporting change and solving these problems, but our educational system needs to evolve to prepare future leaders to take on such human problems. This requires shedding disciplinary silos and allowing students to learn and engage in multidisciplinary dimensions. The development of Harvard SEAS' pedagogy is presented here as an example of a transformation that was unusually concentrated on overcoming the problem outlined by Henderson and Dancy (2011), namely that change rarely focuses "on the situational constraints facing faculty." We built our approach on the work of Henderson and Dancy (2007), who identified situational characteristics that play a role in inhibiting the adoption of "currently available and tested research-based instructional ideas and strategies" in undergraduate STEM education. Presented here are results to date and methodologies for assessment of the interdisciplinary courses with embedded design thinking.

SEAS's mission is to reinvent engineering education for the 21st century, and to create the "21st century engineer." Our focus is on educating students who excel in engineering and applied sciences, but who also have a broad knowledge of other disciplines, and wish to connect advances in engineering to society's most challenging problems. These "T-shaped" individuals – possessing depth in one discipline, but also educated broadly in other disciplines within both the sciences and the arts – are expected to be capable of collaborating seamlessly across multiple fields spanning arts, humanities, natural sciences, and social sciences.

Recognizing that collaboration across disciplines is not easy, we made our required capstone course, ES96, team-based. We also hired faculty with expertise in multidisciplinary collaboration to create two project-based courses designed to train students in this area, and to run a longitudinal research program assessing student outcomes in a subset of our design courses against learning goals, including effective collaboration. These courses, ES21 and ES22, are cross-listed in SEAS and the Graduate School of Design, and are consistently and deliberately among the most diverse courses offered at Harvard. In a typical year, both courses enroll half undergraduate and half graduate students who are studying engineering, computer science, psychology, economics, arts, sciences, humanities, design, law, business, public health, and government. In three of four years, we also enrolled mid-career students.

To create this 21st century engineer, SEAS is finding new ways to engage students, deliver content, collaborate across the university, and connect classroom experiences to the wider world. By investing in innovative new instruction techniques and making engineering more accessible to all students, enrollment in engineering courses has increased steadily since the establishment of the school in 2007. Furthermore, the number of students with Engineering and Applied Sciences concentrations has also increased significantly (see Figure 1).

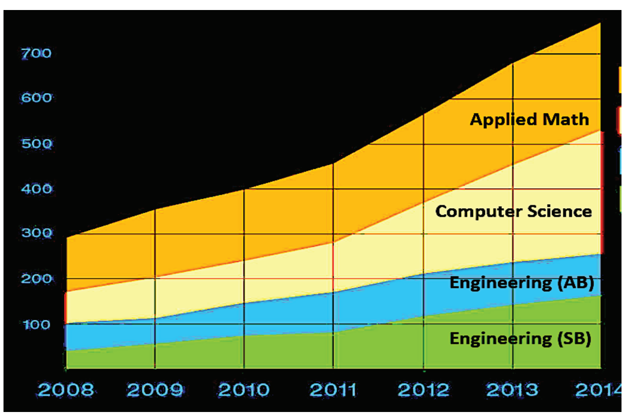


Figure 1. Steady growth in the number of concentrators enrolled in Engineering and Applied Sciences

Educational Mission: Active Learning and Design

SEAS is creating an undergraduate curriculum organized around the premise that engineering and the applied sciences are both *multi*- and *inter*-disciplinary. This philosophy leads to a curriculum with a balance of theory and critical thinking skills, as well as deeply integrated hands-on design projects that provide active learning points throughout the curriculum. By emphasizing problem-solving skills through the application of iterative feedback to a creative idea, SEAS gives every student an understanding of the design process and the tools needed to solve some of the world's most complex problems.

Harvard is among only a few programs in the US to offer both a Bachelor of Arts (AB) degree and an ABET[1]-Accredited Bachelor of Science (SB) degree in Engineering Sciences. The AB degree requires a minimum of 14 to 16 courses for its completion. This degree provides solid preparation for the practice of engineering and for graduate study in engineering, and is an excellent preparation for careers in other professions (business, law, medicine, etc.). The SB degree program requires a minimum of 20 courses, and the level of technical concentration is comparable to engineering programs at other major universities and technical institutions. In addition to the flexible Engineering Sciences AB and SB degrees, SEAS offers rigorous SB degrees in Electrical Engineering and Mechanical Engineering, and an AB in Biomedical Engineering, as well as the flexible Engineering Sciences SB degree.

The curriculum has a multitude of project-based design courses that teach engineering principles in a multidisciplinary context. The following examples of project-based courses demonstrate the different disciplines such courses encompass:

1 The SB program in Engineering Sciences is recognized by the national accreditation agency for engineering programs in the United States: Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, Inc. (ABET).

Computer Sciences 50: Introduction to Computer Science
This course is an introduction to the intellectual enterprises of computer science and the art of programming. Weekly problem sets are inspired by real-world domains of biology, cryptography, finance, forensics, and gaming, and the course culminates in a final project. CS50 is for concentrators and non-concentrators alike, and has the second highest enrollment among all Harvard undergraduate courses (last year 700 students enrolled in this course).

Engineering Sciences 20: How to Create Things and Have Them Matter
Students work in teams to generate, develop, and realize breakthrough ideas centered on a theme. The theme varies every year, and past themes have included "the future of water" and "virtual worlds."

Engineering Sciences 21: The Innovator's Practice: Finding, Building and Leading Good Ideas with Others
Students apply a human-centered design process to stimulate innovation, and focus on the interpersonal elements of multidisciplinary organization and leadership critical for creating and implementing innovative projects in cooperative teams.

Engineering Sciences 22: Design Survivor: Experiential Lessons in Designing for Desirability
Students study real-world cases of how organizations strategically design for desirability. This knowledge is then practiced in weekly design challenges involving prototyping across a range of tools and programs, and applied to diverse industries and target markets.

Engineering Sciences 51: Computer-Aided Machine Design
An introductory course in the design and construction of mechanical and electromechanical devices. The course emphasizes hands-on laboratory work using professional modeling software, and culminates in a team-based design project.

Engineering Sciences 52: The Joy of Electronics
An introduction to designing circuits in the context of solving real problems. The course blends instruction with hands-on lab work, and ends with an open-ended project that challenges students to build on core concepts.

Engineering Sciences 139/239: Innovation in Science and Engineering
This course explores factors and conditions contributing to innovation in science and engineering; how important problems are found, defined, and solved; roles of teamwork and creativity; and applications of these methods to other endeavors. Students receive practical and professional training in techniques to define and solve problems, as well as in brainstorming and other individual and team approaches. This course is taught through a combination of lectures, discussions, and exercises led by innovators in science, engineering, arts, and business.

Engineering Sciences 159: Introduction to Robotics
An introductory course on computer-controlled robotic manipulators. Hands-on laboratory exercises provide experience with industrial robot programming and robot simulation and control.

Engineering Sciences 227: Medical Device Design
A project-based course on the design of medical devices to address needs identified by hospital-based clinicians. Students work in teams with physicians to identify needs and develop a novel device.

In addition to typical engineering courses, SEAS offers cross-disciplinary design focused courses. These will be discussed in detail later. The emphasis on design thinking and experiential learning, as well as peer-to-peer learning (Mazur 2013; Bruff 2009) has

permeated throughout most courses. These elements are integrated within the curriculum and supported by teaching staff and appropriate infrastructure.
For example, the SEAS Teaching Labs host a multitude of state-of-the-art rapid prototyping and testing resources (See: http://www.seas.harvard.edu/teaching-labs). These labs are staffed by professionals with higher degrees in electrical engineering, environmental engineering, bioengineering, chemical engineering, and mechanical engineering. The mission of the Teaching Labs is to provide students with infrastructure and learning using hands-on experiences and tools for problem-solving across multiple disciplines. Students also learn skills through courses, multiple workshops, and a multitude of co-curricular and extracurricular design activities (see Figure 2).

Figure 2. Students engaged in multidisciplinary, project-based learning

Faculty members are also engaged in the activities of the Teaching Labs, and most work closely with the teaching staff in designing appropriate experiments and activities. The teaching staff is responsible for preparing the required infrastructure, whether hardware or simulations. Faculty are frequently present during active Teaching Lab periods and work closely with the Teaching Assistants and staff to ensure that students gain maximum educational benefit from the engagements

The Teaching Labs are also the place where visiting students, from US universities or from other countries, work with SEAS students conducting a variety of projects, some of which are open-ended research projects. These vary in depth and breadth, but all require multidisciplinary problem solving. Examples include dealing with water and air pollution mitigation, green energy generation, designing medical devices, and developing different types of software. Students are also allowed to use the Teaching Labs for creating devices or executing their own ideas, either as individuals or as part of groups and student clubs. In most of cases, students have mentors from the Teaching Labs. A long list of student organizations at SEAS provide additional opportunities for SEAS concentrators to engage with their liberal arts peers to collaborate on real-world problem solving. Students have the chance to show their work through an annual SEAS Design and Project Fair organized by SEAS teaching staff. The fair attracts not only SEAS concentrators but also those from all across Harvard College[2]. The range of projects displayed every spring at the fair is incredibly broad, as dozens of SEAS courses with project components are represented, as well as initiatives.

Many SEAS engineering students choose to increase the depth and breadth of their knowledge by working on extracurricular design projects, either individually or in teams. The goal of these projects is often to implement or disseminate a solution to a problem in the real-world context, outside of the classroom. SEAS encourages students to come up with ideas and projects that may have commercial value; resulting inventions and related IP are owned by the inventing student(s). SEAS does not share or participate in the ownership. Furthermore, SEAS offers financial support for these extracurricular projects through Nectar funding (http://

2 http://www.seas.harvard.edu/news/2010/12/es-51-drives-home-principles-engineering-design

www.seas.harvard.edu/nectar). Nectar is the official funding process at SEAS to support undergraduate co-curricular initiatives, defined as extracurricular initiatives with curricular (technical) content. Students or groups of students working on co-curricular projects are eligible to apply for a semester of funding or longer-term funding. Grants for semester projects are typically $2,000 or less, while long-term projects are eligible for a higher amount. All students engaging in Nectar projects are required to work with a faculty advisor, and those that require physical prototyping space are often supported by the Teaching Labs. Posters from the Nectar projects are displayed at the end of each funding period.

Design Thinking and Problem Solving Across the Curriculum

As mentioned above, SEAS has embedded learning through experiences that incorporate groups across the curriculum. Recently, we asked SEAS faculty to score their courses on percentage of design content. Almost 50% of the faculty responded and the survey results are shown in Figures 3 and 4.

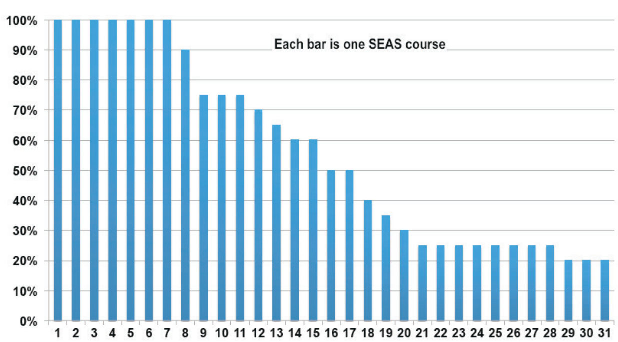


Figure 3. Courses with design content

The survey showed that almost fifty percent of the courses surveyed have significant (more than 50%) design content, and that all disciplines have added design content to their curriculum. To better understand the nature of the design content, the faculty were asked to identify what percentage of the design in their courses is attributed to:

- Problem solving
- Implementation and verification
- Project management and teamwork
- Communication

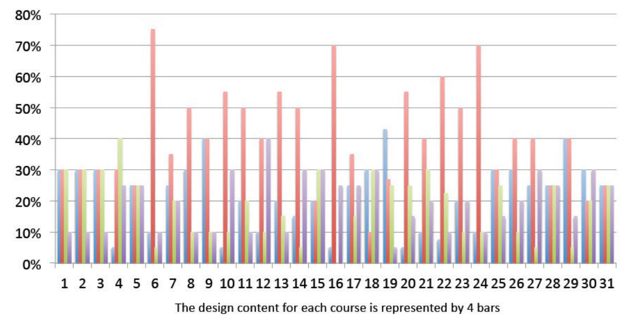


Figure 4. Plotted without a particular order, the design content of each course (problem solving: blue; implementation and verification: red; project management and teamwork: green; communication: purple)

Analysis of this data showed that the design content of the courses participating in the survey emphasized implementation and verification, and then other elements: problem solving, communication, and project management.

Design Thinking and Engineering Capstone Courses

In addition to the typical engineering courses, two courses in particular are offered as capstone design courses and have important and complementary goals. These two courses are dedicated to design thinking and problem solving:

Engineering Problem Solving and Design Project (Engineering Sciences 96: http://es96.seas.harvard.edu)

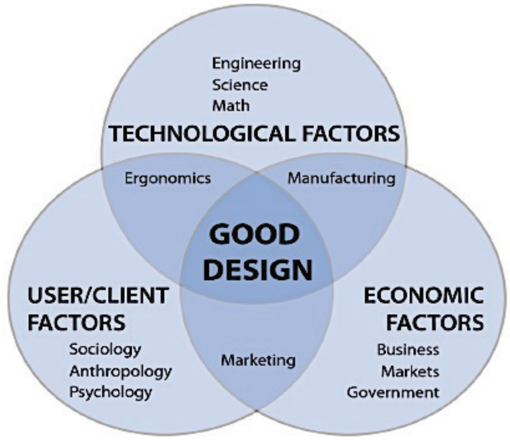
Junior year concentrators and non-concentrators ordinarily take ES 96 over the course of a semester. This team project course iterates through the design process to develop a holistic solution to a real-world problem.

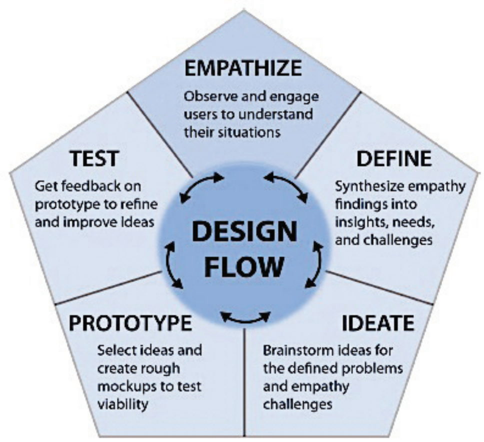
Engineering Design Projects (Engineering Sciences 100)

The design process practiced in ES96 is built upon during this senior year Engineering Design Project. This full-year course is a requirement for all Bachelor of Science (SB) concentrators, and is typically executed as individual projects.

The ES96 course was established about 30 years ago by two SEAS faculty members—Mechanical Engineering professor Fred Abernathy and Electrical Engineering professor Victor Jones—as a complex, multidisciplinary, open-ended, multidimensional problem solving course. Although the course was revised several times, its goal stayed the same: it provides exposure to a range of technical skills, including performance measurement, quantitative analysis, and simulation. Additionally, the course focuses on the user and economic factors that are integral to creating a holistic design solution, such understanding user constraints and needs, problem definition, communication with a client, and documentation and communication skills. It is in ES96 where SEAS students' backgrounds in, and exposure to, the liberal arts are critical for creating cross-disciplinary solutions.

Students play a large role in shaping this course, from setting deadlines to determining leadership roles to managing group dynamics, thus learning critical project management skills. Faculty and Teaching Fellows guide the students through the design process and provide feedback. The model design process is outlined broadly in Figures 5A and 5B.





Figures 5A and 5B

In a typical term session, students work in groups of 10- 20 with a pre-identified client who has a particular problem they would like solved. At the beginning of the course, this problem is only defined as an "area of opportunity," and it is the students' responsibility to further define and articulate the client's problem and come up with a problem statement. Recent past clients and areas of opportunity have included: improving operational sustainability for Harvard University Dining Services; using technology to combat gang-related violence for the Springfield, Massachusetts Police Department; and addressing patient/doctor challenges managing non-healing wounds in diabetic patients for a Harvard medical center. A spring 2014 project was on mitigations for the nuclear disaster at Fukushima.

Students must work with their client as one team to understand the overall context, define the problem, brainstorm possible solutions, propose a solution, and prototype and test the proposed solution. Throughout the course, they break into small sub-teams as appropriate to the granularity of the problem being solved. Students consult their client regularly to obtain feedback throughout the entire design process. Over the years, these solutions have ranged from physical prototypes to written recommendations. The course culminates in an hour-long presentation and detailed report given to the client. ES96 follows a rigorous evaluation of student learning per individual student. A template for the rubric is included in Appendix A below.

The Engineering Design Projects (ES100) course provides a continuation of ES96, but it is an individual engineering design project in which each student will choose and pursue an appropriate capstone project involving both engineering design and quantitative analysis. Each student is supported by a faculty advisor who provides guidance, feedback, and other resources where appropriate. The range of projects undertaken by the students in a given year is vast. A student concentrating in biomedical engineering may work in a SEAS faculty member's lab to develop a neural-activated ankle orthosis, while a mechanical engineering student may work on building a linkage-based continuously variable transmission. In all cases, the students go through the process of identifying a real-world problem area, refining their problem statement, brainstorming solutions, and prototyping and testing their models. The course involves both the design of the product or system and substantial quantitative analysis to verify and validate that the design meets specified requirements. The course culminates in final individual oral presentations and a final report, which constitutes the student's senior thesis.

Lessons Learned

Engineering has a critical role to play in solving the world's most complex problems, but the structure of the educational system and current pedagogy must be enhanced to enable the emergence of a new cadre of leaders that have the capabilities to engage in transformative interventions. Because these problems are very broad in origins and impact, engineering education must become more multidisciplinary. Because these challenges are rooted in the human system, an immersion in liberal arts education is critical.

At Harvard, the realization that deep technical knowledge is necessary but not sufficient has become part of the institutional philosophy and a cornerstone of undergraduate pedagogy. A focus on understanding complex systems and problem solving is a key to mitigating wicked problems. Education with the purpose of enhancing not only technical skills, but also other human dimensions, including design thinking and mindfulness, is of the utmost importance. As a consequence, learning and teaching need to take place in a supportive environment that embraces divergent thinking processes and design methodologies, within an infrastructure that allows for open intellectual exchange, active learning, theory, innovation, and research.

From the discussion presented above, it is clear that a complete ecosystem must be created in order to educate future leaders. Every school must develop and adapt to its own. What took place at Harvard was sparked by the creation of a new school of engineering and facilitated by two consecutive academic Deans, Venky Narayanamuti and Cherry Murray, who believed that a paradigm shift in engineering education needed to take place. In addition, the academic environment, characterized by cross-disciplinary, collaborative research, was fertile for making fundamental changes to the curriculum.

The deans appointed a series of faculty committees to reassess the goals and structure of the entire engineering curriculum. These committees made recommendations from which interdisciplinary education and design became an integral part of the curriculum. These recommendations led to the hiring of design faculty and establishment of modern Teaching Labs that are supported by high-caliber engineers and technicians, ushering in a new era of support for innovation and entrepreneurship. Students responded to these curricular improvements: enrollment in engineering programs increased dramatically. On the university level, a multi-schools initiative, initiated by Harvard Business School Dean Nitin Nohria and supported by the provost and the president, led to the creation of the Harvard innovation lab (i-lab), a new student space to practice and support entrepreneurship (http://i-lab.harvard.edu). Engineering students were the first to take advantage of the i-lab.

The past few years at Harvard represent a textbook situation of enlightened leadership knowing how to drive a progressive agenda, and a faculty believing in the vision and bolstering it. Important enablers of this achievement were a high-caliber faculty that eschewed academic silos and a trans-disciplinary structure that did not include specific departments. For example, the faculty's 2008 report on "Design in the Engineering Curriculum" stated that:

> Engineering Design is the central activity of the engineering profession. It is a creative, iterative, and often open-ended process. Its goal is the conception and development of components, systems, or processes to meet practical needs. A designer works under constraints, taking into account technological, economic, and social factors. Engineering design is usually distinguished from other design activities (industrial design, architecture, graphic design) by its use of science and mathematics to provide insight for predicting the performance of prospective designs.

The report goes on to state:

> The great majority of our engineering students follow one of four career tracks upon graduation: enrollment in PhD programs; professional school (especially medical and business school); technical industry; or nontechnical industry. Design is important for all of these and may be the most transferable skill set of an engineering education. The ability to confront open-ended problems and to marshal the resources necessary to address them is fundamental to design education and a key to our graduates' life-long learning skills, both in engineering research and practice as well as in other professions they may pursue.

With such conviction, design at SEAS started to be embedded throughout the curriculum and co-curriculum. Yet it was believed that there was an additional need to "provide exposure to team-based open-ended real-world problems (ES96) and an independent year-long capstone project (ES100) for all SB students...." This turned out to be a critical notion: create cross-disciplinary courses; yet make sure there are courses dedicated to:

- Address messy, real-world, interdisciplinary problems
- Identify the central needs in problems under constraint and formulate plans to address them (problem setting)
- Explore the extent of the problem space (divergent, creative thinking)
- Develop prototypes as a means of hypothesis testing and exploration
- Use existing technical knowledge (e.g., engineering, science, and math) to model and analyze these problems
- Work effectively on group and individual projects (e.g., personal and interpersonal skills: communication, organization, management, ethics).

Another important element that contributed to the success of this program is the presence of mentors. Students are able to seek advice and guidance from professors and from assistant directors of undergraduate studies (ADUS), individuals dedicated to teaching and advising. The ADUSs are PhDs in Mechanical Engineering, Electrical Engineering, Environmental, Biomedical, and Applied Math, and serve as role model and mentors, as well as lecturers in their own courses that emphasize active learning and entrepreneurship. In addition, the Director of Student Life and the Teaching Lab staff serve similar roles. In discussions at focus group meetings, students stressed the importance of their connection to this group of professionals and fondly described the help they receive from them on academic and social matters

One aspect of preparing engineers to be effective contributors in solving problems is communication and organizational skills. Figure 4 above showed the result of the courses, and pointed out the lack of emphasis on these skills. This is not very surprising, as most faculty members are concerned with technical content. The dedicated design courses ES21, ES22, ES 96, and ES100 emphasize communication and leadership. These skills are required in real-world environments, and thus emphasis must be placed on dedicated, high-caliber design courses that incorporate opportunities to develop them.

During the first few years that ES96 was offered, students were asked about their experiences and, in general, they found the course vague and difficult to follow. They complained about “lack of structure” and ”guidance.” Drilling down to understand what these comments meant, most respondents indicated that they did not know how to obtain the highest grade and that there were no clear assignments or problem sets to solve. A few years later, most students said that the course was the most useful for them in their subsequent work, and many indicated that they learned the most they needed to do their jobs from this course. Graduate students have requested similar courses on design. Although SEAS offers several design workshops, the feeling was that these fall short of a graduate level curriculum. Recently, Deans Cherry Murray and Mohsen Mostafavi (Harvard Graduate School of Design) have agreed to offer a joint master’s degree on design and solving global issues. The design of this program is now underway.

Acknowledgements

The development of this curriculum went through several iterations under the leadership of Deans Venky Narayanamurti and Cherry Murray. Many professors contributed to improvements in content and pedagogy. Although it is difficult to mention everyone here, professors Fred Abernathy, Victor Jones, Rob Howe, Kit Parker, David Mooney, Woody Yang, Jim Anderson, and Karena McKinney made significant contributions to ES96. Professors Rob Wood and Gu-yeon Wei, with several other Faculty members, contributed to the modernization of ES100. The design committee, with B. Altringer, K. Gajos, R. Howe, D. Hwang, C. Walsh, G. Wei, T. Zickler, S. Bhatia, A. Chalah, D. Faas, C. Lombardo, M. Loncar, J. MacArthur, M. Seltzer, P. Ulrich, and A. Uttamchandri as members worked on guiding and improving the content of the design curriculum.

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Appendix A: Student Outcome Assessment Template

Instructions: For each Student Outcome assessed, please score each student on all sub-outcomes.

Scoring: 4 = mastery, 3 = satisfactory, 2 = developing, 1 = unsatisfactory, N/A = don't know, not enough data to assess

OUTCOME (a):	**Student Score**
Ability to apply knowledge of math, science, and engineering	
Applies knowledge (a1)	
Uses precision (a2)	
Draws from relevant areas (a3)	
Understands concepts (a4)	
OUTCOME (b):	
Ability to design and conduct experiments, as well as to analyze and interpret data	
Uses protocol (b1)	
Applies statistical analysis (b2)	
Interprets data (b3)	
Obtains results (b4)	
Meets design objective (b5)	
Uses progression of experiments (b6)	
OUTCOME (c):	
Ability to design a system, component, or process to meet specifications	
Designs to meet specifications (c1)	
Identifies specifications (c2)	
Quantifies specifications (c3)	
Evaluates against specifications (c4)	
Performs review (c5)	
Shows design intent (c6)	
OUTCOME (d):	
Ability to function in multidisciplinary teams	
Demonstrates multidisciplinary thinking (d1)	
Distributes workload (d2)	
Uses time management (d3)	
Shows individual technical contributions (d4)	
Produces team climate (d5)	
OUTCOME (e):	
Ability to identify, formulate, and solve engineering problems	
Identifies problem (e1)	
Formulates problem (e2)	
Proposes potential solutions (e3)	
Evaluates potential solutions (e4)	
Implements solution (e5)	
Evaluates solution (e6)	

OUTCOME (f):

Understanding of professional and ethical responsibility

Understands issues (f1)

Uses judgment (f2)

Aware of code of ethics (f3)

Understands competing values (f4)

Provides explanation (f5)

OUTCOME (g) Communication

Ability to communicate effectively (WRITTEN)

Uses structure and syntax (g1)

Shows perspective (g2)

Uses visual aids (g3)

Creates replicable work (g4)

Uses citations / sources (g5)

Ability to communicate effectively (VERBAL)

Applies structure / organization (g6)

Uses visual aids (g7)

Applies non-verbal delivery techniques (g8)

Applies verbal delivery techniques (g9)

Provides message (g10)

OUTCOME (h):

Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

Understands broad implications (h1)

Uses criteria (h2)

Examines alternatives (h3)

OUTCOME (i):

Recognition of the need for, and an ability to engage in life-long learning

Demonstrates realization of need (i1)

Demonstrates self-teaching ability (i2)

Demonstrates prioritization (i3)

OUTCOME (j):

Knowledge of contemporary issues

Identifies issues (j1)

Understands issues (j2)

Applies to curriculum (j3)

OUTCOME (k):

Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Knows range of tools (k1)

Demonstrates autonomy (k2)

Applies tools to problem (k3)