The sociotechnical core curriculum: An interdisciplinary Engineering Studies degree program

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Abstract

The core curriculum of a unique degree program in Engineering Studies develops sociotechnical thinking and methods. In 1970, Lafayette College initiated this degree program, with the goal of producing graduates who could bridge the gap between engineering and the liberal arts; after 50 years, its mission is to help students recognize the increasingly complex challenges of engineering in the larger framework of socio-technical systems and develop the ability to analyze and understand these systems through multi-disciplinary perspectives. Lafayette's core Engineering Studies curriculum is designed to help students gain expertise in examining the place of engineering and technology in society, with interdisciplinary skills to lead public technology debates around issues related to policy, management, economics, and the environment. When complemented by required coursework in both engineering and the traditional liberal arts, this core course sequence in Engineering Studies gives students an interdisciplinary mindset and identity as "sociotechnical engineers."

In this paper, we describe the development, evolution, and assessment of our core three-course sequence in Engineering Studies. Degree programs like Lafayette's AB in Engineering Studies provide a mechanism for achieving the interdisciplinary, sociotechnical goals articulated by the NAE [1] and others, and for broadening participation in engineering education [2-3, e.g.]. As in our previous paper on the history of this program [4], we will consider both the transferability of our approach to other institutional contexts and its sustainability in our own. While "bridge" remains an apt metaphor for our Engineering Studies program, we hope that it will not be the only such bridge at our College or elsewhere. The development of multiple fluencies and ability to synthesize the methods and mindsets of multiple disciplines are hallmarks of this integrated liberal education in engineering.

Introduction and Theoretical Framework

The core curriculum of our Engineering Studies degree program is uniquely well-designed to address two urgent challenges facing engineering education: to educate interdisciplinary thinkers who appreciate that engineering is inherently sociotechnical, and to broaden participation in engineering.

Sociotechnical Perspective

The view of technologies as socio-technical systems [5] is distinct from a common – but harmful – public understanding of technologies as disembodied machines, mere tools or neutral instruments. As Erik Schatzberg [6] and David Nye [7] have shown, this popular conception of technology is relatively new, having accompanied the modern era of industrial production. What most people have considered technology over the last century had been understood as craftwork and mechanical arts for centuries previous. This distinction is not merely semantic. Craftwork and arts were processes, ways of doing things, and activities. They were dynamic and laborbased, rather than static and product-oriented. The twentieth-century movement toward thinking of technology as objective and asocial propagated the inaccurate perception that technology and society are distinct categories: the former material and technical, the latter human and value-laden. If engineers are defined as those responsible for the design and production of technologies, the view of technologies-as-asocial-things also fosters the image of engineers as working outside of society.

Research in the latter decades of the twentieth century opened up new views of technology that make such a static and a-human concept of technology untenable. This work, grounded in historical and anthropological research and in STS, has revealed the complex and multi-dimensional identity of technologies [8-12]. Schools of thought including actor-network theory, social construction of technology, and social shaping are distinct, though they share a sense of and promote an understanding of technology as mutually social and technical.

Because technologies are designed by people, it follows that technologies are not in fact divorced from the realities of human culture and our attendant moral and political concerns. Those non-technical aspects cannot be checked at the design door, nor held outside of the technologies engineers create. Scholars have established this always-political identity of technologies [13], and further research into the actual operation of technology construction and use demonstrates the value-ladenness of technologies. Technologies are material (and non-material, in the case of computing algorithms and data) manifestations of deeper cultural and political exercises. Examples of this work stretch from the historical contingency of the very idea of technology-as-progress [14], as gendered [15] and racialized [16-17], as tied up in larger political negotiations [12], and as culturally dependent not just because of individual value commitments but even at the scale of national-cultural values [18]. Stated differently and more straightforwardly: to engineer is human.

As the sociologist Steve Matthewman has written, technologies are objects, activities, and knowledge all bound up together [19]. Importantly, once in their material form, they do not lose their intellectual, social character. Casting engineers as socio-technical analysts allows for this dynamism to remain central to the engineers' identity—the engineer works to design systems of social and technical features in an on-going reconstruction of the world.

Broadening Participation

The view of engineers as sociotechnical analysts supports our approach to broadening participation. We may usefully consider the language the National Science Foundation uses to frame broadening participation: a stated NSF goal is to "cultivate a world-class, broadly inclusive science and engineering workforce" [20]. NSF elaborates on "broadly inclusive" as defined by "seeking and accommodating contributions from all sources while reaching out especially to groups that have been underrepresented" [21].

The need for greater inclusion follows from historical patterns of *exclusion*. The data are clear: women and most ethnoracial minorities remain under-represented in engineering education and practice [22]. Despite constituting just over half (51.5%) of the US population, women comprise only 40% of the science and engineering workforce, and just 13% of professional engineers. African-Americans, though 12.3% of the general population, are underrepresented within science and engineering (7.7%) [23]. Underrepresentation is a concern for both utilitarian reasons of economics and prosperity [e.g. 24] and also for moral reasons: it is simply unjust for the world to be constructed by a professional community that does not reflect the demographics of that world.

Interventions and investigations over many years have identified some factors that improve the experience and increase the retention of underrepresented students in engineering. These include: (1) emphasizing the social construction of engineering knowledge, which empowers and liberates students as prospective makers-of-knowledge; (2) emphasizing the social relevance of engineering content, particularly in engineering projects [e.g. 25]; and (3) emphasizing the collaborative, creative nature of engineering design.

The recent tendency to depoliticize engineering instruction and culture is not simply inaccurate; it has also been shown by Erin Cech to be harmful, particularly to those members of engineering communities who may be marginalized [26]. From Cech and Sherick [26]:

> Engineering as a profession prides itself on problem identification, evidence-based solutions, creativity, and entrepreneurship. None of these efforts are devoid of social and cultural contexts, and all require considerations of inclusion to be done most effectively. Engineers' innovations shape the sociotechnical world in profound ways. … It is time for institutional and departmental processes to align with stated goals of diversity and inclusion by challenging the belief that such goals are tangential to "real" engineering.

Thus, creating a curriculum and a disciplinary identity focused on engineering as inherently sociotechnical is a corrective, and it is likely to increase both demographic and disciplinary diversity. In both senses, our intentionally sociotechnical curriculum should broaden participation in engineering discussions, knowledge-making, and practice.

Discussion of "real world applications" has been shown to improve retention rates of women in STEM disciplines [27]. In a study of the expectations of first year college students intending to major in civil engineering, Shealy et al. [28] found that these students, regardless of gender, expected their eventual engineering work to involve important issues such as water supply and climate change. Also, women students were more likely to show an interest in also working to address "far-reaching societal issues." Ro and Knight [29] reviewed a range of studies indicating that women tend to learn better than men when engaged in socially relevant material. A recent survey administered by Microsoft [30] found that 72% of girls and young women say that it is important for them to have a job that directly helps the world, and over 90% describe themselves as creative. Working on socially relevant problems is important to a range of minoritized STEM students including women and students of color, which has been shown by research including studies linking students' personal values to their STEM trajectories [31].

Effectively emphasizing creativity through engineering making has been shown to broaden participation when best practices of inclusion are observed [32]. Strong examples of makerspaces successfully broadening participation and feelings of belonging include some in academic settings [33] and other spaces outside the academy [34]. There exists a risk that such spaces or competitive design teams [24, e.g.] will be dominated by the already-dominant, so intention and attention to the values and goals of hands-on design and making is critical. Our program embeds its values into student design projects by partnering with community members to identify relevant, real-world opportunities for student design *and* by avoiding design competitions that lack deep and meaningful societal context and sociotechnical content.

Like makers of literature, theater, and the visual arts, engineers are fundamentally involved in the act of creating new things, addressing persistent problems with new solutions, and crafting innovative visions and novel approaches while fashioning the infrastructure of our world. To be sure, engineering education requires training in areas that differ from a traditional liberal arts curriculum, most obviously through more specified attention to technical, quantitative, and material knowledge. Yet the core notion that engineering is a creative art offers a range of possibilities for envisioning the engineer as learning in a world common to artists, writers, scientists, and other inventors.

One such possibility is the chance to understand the technologies engineers design not just as things people make and have, but as *activities* people perform, *ideas* people hold, and *social visions* people put into material form. Key to introducing students to this image of engineering are the concepts of technology as a socio-technical system and engineers as socio-technical analysts.

It follows that by presenting engineering as sociotechnical and developing students' interdisciplinary fluency, Lafayette's Engineering Studies core curriculum will also address the need for broadening participation in engineering by: (1) emphasizing the social and political aspects of technology development and distribution; (2) emphasizing that engineering has an ethical responsibility to "do good" for individuals and society; and (3) emphasizing that engineering is a creative process.

Lafayette's Engineering Studies Program

Our program is designed to educate sociotechnical, interdisciplinary, technological citizens. In our institutional context this program has not replaced traditional BS engineering programs, but has coexisted with and complemented them.

Lafayette College initiated its sociotechnical program of study, first known as its AB in Engineering program, in 1970. The College is an undergraduate liberal arts college with strong, ABET-accredited BS engineering programs in mechanical, chemical, civil, and electrical engineering. Lafayette was founded in 1826; its founding charter states that "there be established a College for the education of youth in the various branches of Science and Literature, the useful Arts, Military Science, Tactics, and Engineering." The College offered engineering degrees beginning a few decades later, in 1866.

Lafayette's AB in Engineering program – later Engineering Studies – was proposed in 1969. The rationale presented at the time was: "Society needs more liberally-educated persons with technical backgrounds. The technology to remedy or alleviate many of man's pressing public-sector problems exists; the major obstacles are non-technical—e.g. economic, cultural, organizational, legal, political. This is true of housing, environmental pollution, food, education, and so on. These obstacles require the attention of professionals who know what technology can do, can work as or with engineers, and who have the necessary socio-political inclinations and capabilities." This program was both a natural outgrowth of our College's founding principles of liberal education and consistent with the trends in engineering education in the 1960s, which also impacted other institutions [4]. The influential Grinter report had recommended "a continuing, concentrated effort to strengthen and integrate work in the humanistic and social sciences into engineering programs" [35]. The core curriculum and degree requirements of our AB in Engineering aim to accomplish exactly that.

In more recent calls for educational reform, the National Academy of Engineering envisioned engineers who "will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through a solid grounding in the humanities, social sciences, and economics" and who will "rapidly embrace the potentialities offered by creativity, invention, and cross disciplinary fertilization to create and accommodate new fields of endeavor, including those that require openness to interdisciplinary efforts with nonengineering disciplines such as science, social science, and business" [36]. The American Society of Civil Engineers suggested that "civil engineers will serve as master builders, environmental stewards, innovators and integrators, managers of risk and uncertainty, and leaders in shaping public policy" [37]. Shirley Ann Jackson [38] noted that "there has been continuing concern that engineering education does not sufficiently incorporate liberal studies… As engineering and the technological revolution continue to transform our world, we must assure that those who steer these changes understand the totality of the human condition, and that brings us back to the liberal arts."

As we have noted elsewhere [4], Lafayette's Engineering Studies degree program uncannily addresses both historical and contemporary calls for engineering education to integrate meaningfully with liberal arts methods and values. The challenges facing society today are inherently socio-technical and require collaborative, interdisciplinary solutions – solutions that can be driven by professionals who have solid grounding in engineering and the liberal arts.

We note that our program also addresses a traditional "blind spot" [39] of liberal arts colleges by teaching engineering ways of knowing and doing in the liberal arts context. In this paper, we also address the impact our program has on nonengineering students. Such access to engineering methods and values is essential to prepare students for "active lives as informed citizens" [39-40].

The curriculum for the major in Engineering Studies consists of fundamental courses in math, science, and engineering sciences – selected by each student from an approved list – as well as considerable coursework in the traditional liberal arts. The framework for students to integrate all these courses is provided by a three-course required core curriculum in Engineering Studies: Engineering Economics; Engineering & Public Policy; and Engineering and Society.

The Engineering Studies Core Curriculum

The mission of the Engineering Studies Program at Lafayette College is to help students from a variety of majors connect engineering and the liberal arts (Figure 1). The learning outcomes for Engineering Studies majors, on the other hand (Figure 1), are achieved not only through a combination of coursework in mathematics, the sciences, engineering, the humanities, and the social sciences, but also through a suite of three core Engineering Studies courses. While there are some specific course requirements for the major (detailed in [4]), many of the requirements allow students to choose from among a group of courses. Further, all courses (with the exception of the capstone) are open to any student on campus with the pre-requisites and interest. Thus, the three core courses for the major must do significant work in pulling together students with a variety of skills and knowledge.

The three core courses are Engineering and Public Policy, Engineering Economics and Management, and Engineering and Society (the capstone for the major). The first two are required as pre-requisites for the third and can be taken in either order; each course is offered once per academic year. Students take Engineering and Public Policy and Engineering Economics and Management during the sophomore and/or junior year. Engineering and Society is required during the fall semester of the senior year.

Mission (revised 3/30/15)

The Engineering Studies Program engages students in engineering as a liberal art, recognizing the increasingly complex challenges of engineering in the larger framework of socio-technical systems and examining these systems through multi-disciplinary perspectives.

Learning Outcomes for Majors

1. Demonstrate an understanding of engineering as a socio-technical activity;
2. Apply multi-disciplinary perspectives to understand, formulate, analyze, and develop sustainable solutions for complex problems;
3. Demonstrate an understanding of ethical leadership and professional responsibility;
4. Integrate multiple and diverse perspectives in defining and solving engineering problems in cultural context;
5. Work effectively in teams; and
6. Explain and communicate effectively solutions using visual, oral and written techniques to diverse audiences.

Figure 1. Current mission and learning outcomes for the Engineering Studies Program.

Engineering Economics and Management

According to Lafayette College's course catalog, Engineering Economics and Management "addresses the concepts and analytical techniques of engineering economics and management. Topics include present and annual worth analysis, rate of return analysis, benefit/cost analysis, capital budgeting, scheduling, optimization, and decision-making under uncertainty." Over the last seven years, the course was taught primarily by one instructor, with the exception of spring 2019.

The learning outcomes have remained relatively constant over this time; the spring 2020 course outcomes are that by the end of the course, students should be able to:

1. *Understand, formulate, analyze, and develop solutions for problems involving engineering economics and management.*
2. *Evaluate, on the basis of economic criteria, alternatives that are equivalent in terms of engineering criteria using: cash flow analysis, present and annual worth analysis, rate of return analysis, benefit/cost analysis, replacement analysis, breakeven analysis, and considerations of risk and uncertainty.*
3. *Address issues associated with managing engineering functions, including managerial accounting and capital budgeting.*
4. *Discuss current topics related to engineering economics and management.*
5. *Explain and effectively communicate solutions to engineering economics and management problems using graphical, oral, and written techniques to diverse audiences.*

In short, after completing the course, students should be able to understand the economic implications of various courses of action.

The course has been taught as a fairly traditional course on engineering economics, using a standard textbook. The learning activities and format for the course have varied depending on the instructor. The instructor who taught the course in Spring 2019 used a traditional lecture/homework format. In other recent semesters, the instructor has designed a partially "flipped" format. In this format, to prepare for class meetings students are asked to read one or more sections of the textbook, watch one or more short video clips, and attempt 1-3 problems based on the concepts in the reading(s)/video(s). In class, then, the instructor briefly highlights key concepts and students have the opportunity to ask questions. Students spend the remainder of the class period working in small groups to solve additional problems using the concepts of the day. The video clips are recorded by the instructor and include text, real-time writing to work through numerical problems, and the instructor's voice highlighting concepts and narrating the problem-solving. Students complete individual quizzes approximately every two weeks throughout the semester and take a comprehensive final exam.

Over the last five years our Engineering Economics & Management course has enrolled 176 students, with an average of 29 students per offering. Those students have been 39% female, and 29% of those who chose to specify an ethnoracial identity identified one under-represented in engineering. The majority of students have been Engineering Studies majors, but students have enrolled from a variety of majors, including economics, mechanical and civil engineering, government & law, and psychology. In the last five years, 16% of the enrolled students have pursued non-engineering majors.

Engineering and Public Policy

Engineering and Public Policy is cross-listed as Introduction to Public Policy and serves as a required introductory course for both Engineering Studies and the college's Policy Studies major. To meet the needs of these two populations, this cross-listed course is taught as an introductory policy course with a focus on engineering, science, and technology policy. The course objectives in the syllabus state, "Our society needs policy makers who understand the importance of science and engineering, who appreciate the power of the scientific method, and who are prepared to grapple with the complex nature of technology. Similarly, we need scientists and engineers who are prepared to think broadly about the political, social, and ethical nature of their work, who are dedicated to effectively communicating their work to policy makers and the general public, and who understand the complex and messy nature of policy making. To those ends, the broad objective of this course is to give policy and engineering students a foundation in science and technology policy." Over the last seven years, the course has been taught primarily by one instructor, with the exception of the fall of 2019.

The learning outcomes for the course have been designed to accommodate students from both the Engineering Studies and the Policy Studies majors. They are that upon completion of the course, students will be able to:

1. *Define public policy and explain its accepted rationale, especially in terms of science and technology policy*
2. *Appreciate the complex technical, social, ethical, political, and economic nature of science and technology policy and identify important stakeholders*
3. *Describe policy process model and identify the common steps in real-world science and technology policy examples.*
4. *Apply policy analysis tools to science and technology policy issues, specifically:*
    a. *Defining and analyzing the public problem*
    b. *Constructing policy alternatives to address the problem*
    c. *Choosing appropriate evaluative criteria*
    d. *Assessing the policy alternatives*
    e. *Drawing Conclusions and making recommendations*
5. *Develop skills for creating concise graphical representation of data, including*
    a. *Identifying and retrieving data relevant to particular questions*
    b. *Interpreting and creating informative charts, figures, and infographics*
    c. *Working with geographical data systems*
6. *Develop skills for life-long learning by independently learning about areas of interest*
7. *Demonstrate an ability to work well in multi-disciplinary teams and value multiple perspectives*
8. *Formulate original ideas that draw on course materials and communicate them verbally, graphically, and in writing.*

The course includes three hours per week of lecture and discussion (in two class meetings) and two hours per week of "lab," in which students work in groups on activities and relevant skill building. It is offered every fall, with two lecture sections (capped at 22) and three lab sections (capped at 15). The course and has been at or past capacity each fall for the last 5 years, with an average enrollment of 23 per class section and a total enrollment of 231.

Over the last five years, 68% of students enrolled in the cross-listed class were enrolled in Engineering Studies (as opposed to Policy Studies). Furthermore, the students enrolled in *Engineering and Public Policy* over the last five years have been 40% female, and 29% of those who chose to specify an ethnoracial identity identified one under-represented in engineering. While many of those students are Engineering Studies majors, both the Policy Studies and Engineering Studies enrollment options draw students from a wide range of majors, notably Economics, Government and Law, and Environmental Studies, but also across the college's four academic divisions, including Film and Media Studies, Art, History, Biology, Chemistry, Civil Engineering and Mechanical Engineering. Approximately a third of enrolled students are **not**

Engineering Studies or Policy Studies majors, reflecting the class' effectiveness in broadening participation in *Engineering and Public Policy* discussions and methods.

The course is a unique offering unlike other undergraduate courses we know of, which tend to focus only on introducing public policy or, perhaps, on science and technology policy without the broader policy topics. Students learn about and then implement policy analysis, a policy decision making tool that is comparable to engineering problem solving and the scientific method. Class sessions are structured with a mix of short lectures, whole group discussion, small group discussion, and a range of approaches to facilitate student engagement in their learning. These approaches include think-pair-share, forming groups based on interest in a particular topic or question, informal debates on questions with multiple defensible positions, and communal/group idea mapping. As students learn about concepts in public policy, they are given opportunities through discussion and assignments to apply their understanding of those concepts to relevant policy issues.

Labs provide opportunities for students to build important and relevant skills. A series of four labs teach students skills for assessing the logic of arguments and the evidence provided and then making and supporting arguments of their own. In the first of these labs, students review two opposing op-eds and analyze them carefully based on the formulation of their arguments, the evidence they provide, and their language. The next three labs are a series of debates that give students more experience making and assessing evidence-based arguments, as students not assigned to debate in a particular week have the task of assessing the arguments made by their peers. Other skills covered in lab include evaluating and creating concise graphical representations of data, including charts, figures, and infographics; learning to use Social Explorer, an accessible and easy to learn GIS tool; and research and presentation tools for their large policy analysis projects.

Engineering and Society

The senior capstone seminar in Engineering and Society is the culminating experience for seniors in the major. It is a one-semester course structured as a hybrid between discussion-based seminar and project-based workshop. The general theme of the course focuses on the place of engineering and technology in society. It examines the ways cultural values shape technologies, social foundations define the role of engineers, and engineers influence the broader world in efforts to achieve progress. Students apply the knowledge they have gained from both engineering and non-engineering courses to tackle these engineering/society relationships. In this vein, the course takes the lessons of political philosophy, historical context, cultural awareness, communication, technical proficiency, economic theory, and environmental knowledge from the class prerequisites and applies them to original projects on campus and in the Lehigh Valley region.

The hybrid nature of the course means that the first third of the semester confirms the common language and theoretical commitments of studies in engineering and society. In this seminar portion of the course, students play an active role in managing the classroom—leading sessions, presenting results, organizing classes, and discussing material. The latter two-thirds task students with applying that basis to their projects about technology in cultural context.

The learning outcomes for this course are that at its conclusion, students will be able to:

1. *Conduct analyses of the cultural contexts of technologies and engineering.*
2. *Apply knowledge from your undergraduate curriculum to these analyses.*
3. *Demonstrate that your project research is part of an ongoing conversation among scholars.*
4. *Identify social, ethical and economic issues surrounding the information you use in that project.*
5. *Develop organization, management, and teamwork skills.*
6. *Demonstrate proficiency with a variety of communications skills.*

The course activities and discussions are grounded in student reading from two books [41-42] and a series of articles. Projects have included analyses of the Lafayette College food loop and establishment and maintenance of the College's organic farm, as well as several community-based projects, including the design and implementation of an interactive "musical playground" installation on a local "arts trail," a project that has been honored for its community-College partnership. Projects also often address matters of campus value. Recent work, for example, conducted research to support the College's adoption of a Climate Action Plan aimed at achieving carbon neutrality by 2035. As a few examples, students in capstone seminars in 2017, 2018, and 2019 assessed the capacity for campus buildings to hold solar panels, investigated options for microgrids on certain quads on campus, and helped the Office of Sustainability assess the economic implications of bringing biogenic fuels to the College's power plant.

The 114 students enrolled in *Engineering and Society* over the last five years have been 39% female, and 25% of those who chose to specify an ethnoracial identity identified one under-represented in engineering. Since 2017, registration has been limited to Engineering Studies majors; prior to that restriction, approximately 4% of students in Engineering and Society were non-engineers, and the class was popular with mechanical and civil engineers as well.

Student Experience and Outcomes

In their capstone experience (*Engineering and Society)*, Engineering Studies majors are asked to reflect on their paths through the major and how they have achieved the learning outcomes for the major. Some examples of student responses, excerpted from these autobiographical essays, include:

- "I developed a greater understanding for human interactions with new technology and realized the different levels of technological proficiency throughout the world, thus, helping me to understand the implications public policy has on the world when dealing with technology in relation to products and the environment."
- "I gained an understanding of the impact the built world and urban infrastructure (designed predominantly by civil and environmental engineers) had on the social ecosystems which they encompassed. Rather than a drive to help those in 'need' … I had now developed a consciousness for the positive and negative impacts of engineering systems and design on economies, cities, governments, and societies."
- "One of the most valuable skills that [the program] has taught me is this skill of asking 'why' not 'how.' Asking 'how' typically results in a methodological solution, rather than

a solution that conveys understanding. Asking 'why' instead of 'how' has resulted in a better understanding of the reasoning behind things, as well as an increased awareness of the methodology."

- "Contextual understanding is the greatest strength a senior engineering studies (EGRS) major possesses and while other Engineers are trained to problem solve with their design goals in mind, EGRS majors are taught to go beyond the straight-forward analysis and consider other, non-technical factors. EGRS look towards social, economic, and political factors (among others) to fully comprehend the problem at hand. In doing so, EGRS majors are better equipped to make informed decisions on project alternatives. This ability to understand the subtle nuances of complex technical problems makes EGRS majors the intermediary between traditionally trained engineers and society."
- "The impact of EGRS' tailored experience isn't derived from each individual class. Rather, the EGRS curriculum as a whole served to change the way I worked and communicated. The sum total of my engineering studies experience didn't simply teach me facts. It changed the way I think."

Further, the capstone instructor has observed students' explicit incorporation of tools and methods learned in the two prerequisite courses into their work. An exemplary quote from one student essay indicates that students agree:

- "The core classes of EGRS serve as good foundations for the major, looking at engineering economics and policy to mold students minds into thinking about the humanities of engineering."

In *Engineering Economics*, students analyze the financial implications of choices that engineers, engineering firms, or public agencies might need to make. Quantitative assessment in the course relies primarily on quizzes/exams in which students are asked to "translate" a written situation into a numerical analysis and interpret the numerical results. The questions (as well as those the students work on in class throughout the semester) are always in context, and although the focus is on the numerical analysis, these contexts include ethical, environmental, or social considerations. For example, a typical question might ask students to calculate benefit cost ratios for alternative transportation projects that have different costs and benefits, some of which may be easily expressed in dollar amounts and others of which may not be. Further, most classes begin with a discussion of a "current event" – something that is in the news around technology and engineering that has a clear economic component. The discussion includes both how we can apply the engineering economic analysis techniques we are learning to the situation as well as what other factors might influence the decision and how. They go on to apply these considerations to their projects in the capstone course.

The first half of the semester in *Engineering and Public Policy* focuses primarily on policy concepts, such as those listed in Learning Outcomes 1, 3, and 4 above. The midterm exam is a mixture of multiple choice, short answer, and long answer questions and asks students to demonstrate their understanding of basic policy processes and actors and connect these to technology related problems such as climate change, gun violence, and STEM education. The second half of the semester is focused on science and technology policy more specifically as well as technology policy topics. Assignments in this course are all writing assignments. In the first half of the semester, students turn in three "Curiosity and Connections" assignments designed to encourage students to research science, technology, or engineering policy issues of interest to them and apply their new knowledge of policy concepts covered in class to their chosen topic. Assignments in the second half of the semester are drafts of sections of their policy analysis project. The drafts receive significant instructor feedback to enable success of this ambitious project. Over the years, the policy analysis project has taken two forms. In one, each group of 4-5 students selects a national science, technology, or engineering policy topic (e.g. aging transportation infrastructure, fracking, etc.) and conducts a policy analysis of the problem and potential policy solutions. In the second, each class section is assigned a local policy problem (e.g. low recycling rates, local climate change adaptation or mitigation, etc.), and again students work in groups of 4-5 to conduct a policy analysis. Presentations of their work to their classmates, and as applicable, community stakeholders make excellent capstones to the semester.

Enrollment trends and demographics in the core classes also provide an indication of the effectiveness of these courses in broadening participation. Figure 2 shows the enrollment patterns since 2000 in all three courses, showing a consistent student demand for such courses; observed fluctuations are more strongly linked with available faculty resources than with student interest.

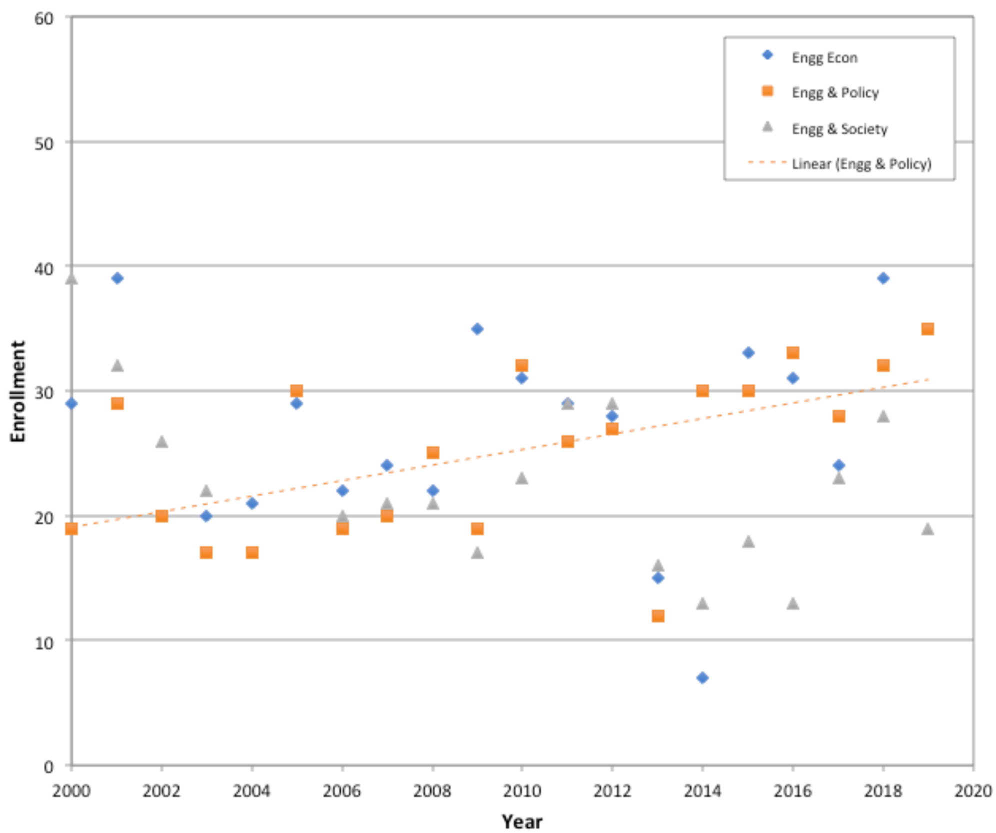

Figure 2. Twenty-year history of enrollments in the three core classes.

Figure 3 shows the demographic distribution of students in the three core classes, relative to our institution's standard engineering courses that do not emphasize sociotechnical methods or values, and to the demographics of the College's non-engineering student population.

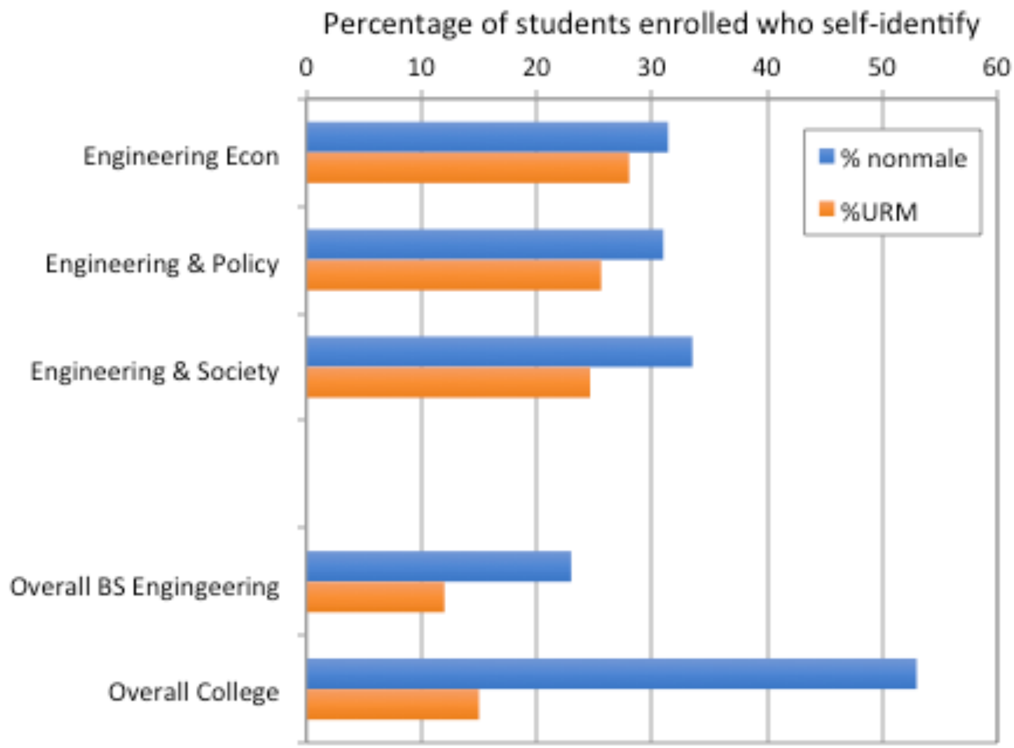

Figure 3. Twenty-year averages of demographic distribution in core courses.

Students in these core Engineering Studies courses are more diverse in terms of gender than are Lafayette College students pursuing BS degrees in engineering, and they are more diverse in terms of ethno-racial identity than both those pursuing BS Engineering degrees *and* students pursuing degrees in disciplines other than engineering. Clearly, the Engineering Studies courses are welcoming to women and students from under-represented backgrounds, and these courses are "broadening participation" in engineering education and discussions. However, the authors have some concern that when enrollment numbers are reported for all of the Engineering Division, the relative proportions of women and students of color in Engineering Studies can mask the underrepresentation in other engineering majors.

Conclusion

The courses and curricula developed for Lafayette College's Engineering Studies program have been innovative, interdisciplinary, and effective in helping students and faculty negotiate with sociotechnical systems and thinking. We have found team teaching and cross-listing of courses (e.g. in Engineering Studies and Policy Studies) to be useful ways to model and signal the interdisciplinary dialogue and connections involved in our major. Even when courses are not team taught, the involvement of multiple programs in developing syllabi and learning outcomes ensure that multiple disciplinary perspectives are represented in our program's core classes. We also strongly encourage the scaffolding of sociotechnical and STS concepts in a multi-course sequence, to enable students to progressively develop a more sophisticated understanding and skillset.

The societal and sociotechnical needs to which our program's creation responded to are still—perhaps even more—relevant today. Many of our most persistent sociotechnical challenges, from slowing or mitigating climate change to considering the accessibility, inclusivity, and impact of new technologies, exist in the spaces between traditional disciplines; meaningfully addressing these challenges will require the intentional combination of multiple approaches and methods. In this context, recognition of the sociotechnical nature of engineering and broadening participation in technological education, citizenship, and practice are urgent priorities.

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