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Innovating Engineering Curriculum for First-Year Retention

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Innovating Engineering Curriculum for First-Year Retention

Abstract

An ongoing effort to improve retention rates for first- and second-year engineering students at Clarkson University has resulted in the modernization of the curriculum including 1) the design, development, and rollout of a new course that emphasizes the links between engineering and society for first-year students, and 2) the introduction of a more flexible first year curriculum that offers two paths for incoming First-Year Engineering (FYE) students. The new course was piloted in Spring 2011, has grown into a key element of the modernized curriculum, and was made required for all first-year engineering students beginning in the 2014/15 academic year. In the context of engagement as much as retention, significant changes have been made to the new course curriculum to increase the active learning opportunities offered to the students as well as to link the various elements of the course (e.g., class activities, team-based design project, and summative assessments) to the engineering challenges facing engineers and society today. ABET assessment results demonstrate that the students are not only meeting expectations for the course but also for several key "ABET Criterion 3. Student Outcomes" through the exploration and study of real-world engineering and technological problems. The course addresses ABET criteria (c), (d), (f), (g), (h), and (j); recent assessment results will be presented for (c), (f), and (h), which are emphasized in the course. The impacts of the course on the students' attitudes towards engineering are being assessed with a combination of qualitative and quantitative approaches, including the administration of a survey each semester at the beginning (pre survey) and at the end of the semester (post survey). A qualitative analysis of student responses to a pre- post-survey indicates that students are responding positively to the course structure, are more engaged in engineering itself, and have gained a better understanding of the interrelationships between engineering and society; a quantitative analysis of the survey results will be conducted later this year. An analysis of recent data indicates both an improvement in student performance in other FYE required courses as well increased retention of FYE students in the engineering programs the period 2010/11 to 2013/14.

Introduction

Clarkson University is a small, technologically-focused research university with a total enrollment of approximately 3500 students (3000 undergraduate and 500 graduate students); engineering majors comprise over half of the undergraduate enrollment. An ongoing effort to improve the engagement and retention of first- and second-year engineering students has resulted in the modernization of the curriculum including 1) the design, development, and rollout of a new course three-credit course entitled *ES 110 Engineering and Society* that emphasizes the links between engineering and society for first-year students, and 2) the introduction of a more flexible first year curriculum that effectively decouples the first physics course from the first calculus course by "delaying" the first physics course until the second semester. Specifically, the Wallace H. Coulter School of Engineering Strategic Plan of 2007 included as one of its strategic goals to modernize the first year experience. Specifically, this goal was stated as, "All students in the School of Engineering will have a first-year Technology course that provides a small-class, hands-on, query-based learning experience that ties technology to society and engages students in engineering problem-solving."

Curriculum modernization

While ABET (Accreditation Board for Engineering and Technology, Inc.,) specifically requires that engineers "meet a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives," ABET also suggests a particular responsibility for engineers to study the social context of technology; the new course is designed to do just that. The first part of the curriculum modernization effort was to design a course 1) to introduce FYE students to engineering concepts and to enhance the engagement of first-year engineering students (FYE) with engineering faculty and the field of engineering in general, and 2) to meet the strategic needs of the School of Engineering as well as curricular requirements for majors of the other two schools ("Non-majors" or NM).[1] The new engineering and society course both satisfies general curriculum requirements for engineering and non-engineering majors and offers engineering majors early exposure to key concepts relevant to several ABET Criteria. In particular, it provides non-engineering majors with an exposure to the engineering profession including the opportunity to work on a multi-disciplinary design team. The course content focuses on the complex relationships among engineering (including the design process), technology, and society. The course is designated as a 'Science, Technology, and Society' (STS) knowledge area course as well as a 'TECHNOLOGY' (TECH) course. The second aspect of the curriculum modernization was to change the first-year curriculum from a completely common first year to a more flexible curriculum that offers two paths in order to increase the chances of academic success for all students, especially for those students who have been identified as less well prepared in mathematics.[2]

<u>Flexible first-year curriculum with new course</u>

Under the previous common curriculum, all incoming engineering majors (excluding Engineering and Management) were enrolled in the first calculus course in parallel with the first physics course, the first chemistry course, a "University Seminar" course, and a "First-Year Seminar" course unless they had earned Advanced Placement or college credit that could be transferred for these courses. In the spring semester, all FYE students were enrolled in the second calculus course, the second physics course, and the second chemistry course; each student also selected a "Knowledge Area" elective.

The first path of the new curriculum closely resembles the original common curriculum, but the general Knowledge Area elective chosen in the second semester is replaced with the new engineering and society course. Students on the second path have been identified as less well prepared in mathematics through the use of mathematics and physics proficiency test scores, though in depth discussion of this initiative is beyond the scope of this paper.[2] In the spring semester, these delayed students are enrolled in the first physics course in parallel with the second calculus course. The intent of delaying the physics class is effectively to decouple the first calculus course from the first physics course with the objective of enabling the delayed students to achieve improved academic performance in both of the courses. Students on this path are enrolled in the second physics course in the fall of the second year. The remaining FYE students enrolled in the fall are typically students with incoming college transfer credit or advanced placement (AP) credit such that this was a logical course for them to take during the first semester in lieu of courses for which they already had credit. In addition, approximately five slots in each section were open to non-majors of any year.[1] Beginning in Fall 14, unless a student has special academic needs, all FYE students are enrolled in the new course with about half taking it each semester.

Since the pilot offering in Spring 11, the course enrollment has grown from a single section with 33 students to sixteen sections with a total enrollment of approximately 251 students each semester; each section typically has five slots available for non-engineering majors. Prior to the 2014-2015 academic year, eight sections have been offered in the fall and six sections in the spring as not all of the remaining FYE students chose the course as a KA elective, though the majority were advised to. For 2014/15, all of the engineering departments made the new course required for all incoming FYE students with the exception Engineering and Management (E & M) majors, who may still choose it as an elective, and cohorts of students enrolled in special programs (e.g., Honors, transfer students) or who have selected certain minors with specific elective course requirements. In response, for 2014-2015 and beyond, eight to ten closely coordinated sections of the course are being offered each semester with a typical makeup of 25 FYE students and no more than 5 non-majors including E&M; due to demand, enrollment in certain sections was increased to 40. Total enrollment grew from 330 in 2011-2012 to 358 in 2013-2014 and is estimated to reach a total of approximately 500 in 2014-2015 with the change to a required FYE course.

With the course objective of engaging FYE students with engineering faculty, it is significant to note that throughout this time, the course has been taught by a team of instructors the majority of whom have advanced engineering degrees in different engineering disciplines (CHE – 1, EE - 1, ME - 3) and varied experience (Government, small and large engineering firms, K-12 education, as well as college and university employment), including the Associate Dean of the Engineering School, who has been instrumental in the design, development, and deployment of the course. The team has developed and used closely coordinated formative work including guided reading questions and class activities as well as common summative assessments (both quizzes and exams). The interdisciplinary nature of the team has been extremely valuable to the ongoing evolution of the course.

Course description

While most students broadly accept the notion that our society is shaped by technology, the converse relationship is less apparent. It is a goal of the course for students to gain a broad understanding of the complex relationships among engineering, technology, and society including the variety of ways that society does influence the development of technology, including its adoption or rejection. The course also emphasizes the importance of ethics in all aspects of engineering decision-making from design decisions to project management. The course design departs from the more common first year engineering course consisting of design, engineering ethics, engineering problem solving and engineering topics, by fusing a scaled-back version of such content with content addressing concepts and knowledge associated with engineering, technology, and society; it *excludes* most of the engineering problem solving and *emphasizes* the interactions among engineering, technology, and society. Our approach is supported by the work of Geselowitz and Vardalas, and our experience to date has been that it is working well.[3-4]

The course objectives meet the needs of an engineering class and the course is designated as both a technology (TECH) course and a science, technology and society (STS) knowledge area course within the University's required common experience for all students. The learning outcomes are included in Table 1 with reference to the ABET Criterion 3 program outcomes. With the STS focus of this class as well as the in-depth analysis requirements, many of ABET's program outcomes are addressed.

Course outline

The course outline shown in Table 2 illustrates the breadth of topics that are included in the course. The progression of topics has evolved from an initial serial coverage from engineering, to design, to ethics, and then to technology/engineering and society to a progression that allows the interrelationships among the topics to be emphasized throughout the course. Key concepts such as engineering design and engineering ethics are woven into the subsequent discussions of the Technology and Society topics. Topics identified with an "*" are discussed in more detail in the body of the paper. The sources for the course are listed below, and a simplified description of the linking of the topics follows.

- *Engineering & Society,* Chapter 1: *Engineering & History* (Johnston, et al.)[5]
- *Beyond Engineering: How Society Shapes Technology* by Robert Pool[6]
  Note: Each concept developed in this book is applied to nuclear power, though Pool also applies each concept to at least one additional complex technology.
- Custom textbook covering engineering design and engineering ethics that was created using the Pearson E Source texts by Horenstein[7] and Fleddermann[8]
- Supplemental material compiled from various texts with content on the sociology and history of engineering and technology such as Johnston and Petroski[5, 9]

- Various supplemental material especially for current event examples not addressed in the text (e.g., documentaries, articles)

Table 1: *ES 110 Engineering and Society* Learning Outcomes and ABET Criteria

Course Learning Outcome – Students will demonstrate:	ABET*	Assessment
An understanding of and an ability to use the engineering design process.	a, b, c	design project
An understanding of value systems and ethics and be able to relate these concepts to professional problems.	f	HW, exams
The ability to recognize and analyze environmental, social, political, ethical, health and safety, and sustainability considerations and impacts of engineering design.	c, f, h, j	HW, discussion, exams
An appreciation of the need for critical assessment of the sources of information, including computational tools, used to solve engineering design problems.	c	HW, discussion, design project
An understanding of the major engineering disciplines and be able to identify the core scientific disciplines underlying these. They will demonstrate an understanding of how the engineering profession intersects with the sciences and mathematics.	d	HW, exams
The ability to effectively communicate their ideas in written and oral formats.	g	class activities, design project
*(a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (d) an ability to function on multidisciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; (i) a recognition of the need for, and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.		

The first topic of the course emphasizes that throughout history, engineers have used their knowledge and experience to create good designs that serve as solutions to societal problems. This is true today though the nature of the technology has become much more complex as have the organizations that develop it. These topics lead to the topic of engineering design including current engineering challenges. This topic emphasizes that 'good engineers' follow the engineering design cycle in order that their designs meet all performance specifications, but this has become more challenging as technology has become complex and thus more unpredictable. These topics in turn link directly to the role of ethics in the context of engineering decisions. All of this underlies the later discussions of the development and public acceptance of technology in which it is emphasized that while most technology is developed in response to societal needs, the adoption of these technologies typically comes with some associated cost or risk. Thus, it is also the engineer's responsibility to consider these negative impacts. This allows a broader discussion of ethics in the context of both the development and introduction of a new or revolutionary technology and the consideration of a large engineering project (e.g., dams, nuclear

Table 2: Course topics progress to allow connections to be made between them

Unit 1: Introduction[5,7,9]

What is engineering? (Also: mathematics, science, and technology)
- What are the relationships among them?
- Exploring Engineering Disciplines*

History of Engineering and Technology
- Nature of technology; public acceptance of technology
- Socio-technical systems

Technology and social change

Unit 2: Engineering Design[7,13]

- Engineering design cycle; good designs; specifications
- Societal need & NAE Grand Challenges*
- Design Project* (interdisciplinary self-selected design teams)

Unit 3: Engineering & Society Part 1[6]

Pattern of Innovation (Normal technology ⇨Technological Revolution ⇨ Normal Technology)
- Nature of the inventors, nontechnical factors, momentum
- Technological Revolutions and learning curve

Unit 4: Engineering Ethics[8]

Framework and tools for solving open-ended ethical problems*
- Values, norms, conflicting values, value systems
- Role Play: *Fly – Not Fly**
- Identify and clarify factual, conceptual, and moral issues*

Application of ethical theories
- Case Studies* - Various including:
    - Space shuttle *Challenger**
    - Union Carbide, Bhopal, India

Unit 5: Engineering & Society Part 2[6]

Additional factors affecting technology development (Activity: Technological Revolution)
- Organizations, leaders, business decisions, momentum
- Complexity of modern technology
- Technological Lock-in

Risk of modern technology (Activity: “Town Meeting”)
- Complexity and impact of design choices
    - Case study: DC-10
- Risk assessment (deterministic, probabilistic)
- Perceptions of risk and social construction of knowledge

Role of general public in control of modern complex technology (Activity: Documentary)

Complex technology as a Faustian Bargain
- Case studies: BP *Deepwater Horizon*, Union Carbide, Bhopal; *Challenger*

Design approaches for complex technology
- Technological solutions
    - Case Study: Rebuilding of CFC Industry
- Inherent safety

*** These examples are described in the text of the paper.**

power, chemical plants, pipelines, etc.). Finally, modern design approaches (e.g., human factors engineering, inherent safety, technological solutions, etc.) are discussed as ways not only to make inherently complex technology as safe as possible but also, because the associated risk to the public and to the environment is drastically reduced, to facilitate public acceptance of these technologies. The course was piloted in a lecture-discussion format.

Innovations for active learning

Over the course of the past several years, the team of instructors has introduced innovations to the course in order to decrease the focus on the instructor, increase the emphasis on active student learning, and provide students with opportunities that encourage them to think of themselves as engineers as well as to ensure that the particular needs of millennial students are being met. Recent research on motivating modern learners indicates that it is important to enable “the millennials” to overcome anxiety and believe that they can learn content and achieve the outcomes; they must build self-efficacy and take responsibility for their own learning. According to Pryce, some of the best ways to motivate the millennial student are through guided practice, repeated and distributed practice, and early and frequent “low stakes formative assessment with developmental feedback, as well as repeated and distributed practice built into the course structure.”[10] Thus, the development of appropriate class components and assessments is essential, especially for a course aimed at first-year students. The assessments must: 1) be perceived as both relevant and valuable to the students; 2) be designed in such a way that the instructors can provide prompt and relevant feedback to the students; and 3) be designed to assess key learning outcomes. In addition, to help students internalize the unfamiliar dimensions of the role of college student, Voge suggests that instructors make clear the demands the course design places on the students and to explain the functional design of the course. Specifically, instructors should explain the various components of the course and their functions, outline expectations for students with respect to each component, and advise the students on how to align their actions with the course design.[11]

As noted by Barkley, learning is a dynamic process in which the learner literally builds his or her own mind by constantly making and changing connections between with is new and what is already known. Further, as it is just not possible for teachers to transfer knowledge into learners’ brains, the students need to do the work required to learn. Thus, course innovations can be designed not only to help students develop metacognitive skills (e.g., previewing, summarizing, paraphrasing, note-taking), empowering them as active partners in their learning, but also to provide students with the opportunity to do the work required to learn.[12]

In response, recent innovations to the course not only increase the emphasis on active student learning but also provide students with opportunities that encourage them to think of themselves as engineers by linking the formal course content to assignments and assessments that directly relate to the to the students’ future professional lives (e.g., real-world problems, “decision-making). Each of the course topics is covered with a similar combination of reading questions, class activities, reflection opportunities, and a closely-linked summative assessment in the form of a "concept exam" that serves as a part of the actual learning process. The various assessment categories allow more frequent, more appropriate assessments that are organized to link closely with the key concepts. As the semester progresses, the similarity in the coverage of the topics and the form of the assessments further enables the students self-efficacy, empowers them as active partners in the learning process, and provides them with the opportunity to do the work required to learn.[12] The final exam is cumulative and assesses the students broad understanding of the topics covered throughout the semester.

Voge notes that course assessment and grading methods should be designed and aligned to ensure students are spending more time and effort on the most important tasks/elements of the course.[11] The course grading structure, as shown graphically in Figure 1, in particular the strong weighting of the preparatory elements and the concept exams, should signal to the student not only that significant time should be dedicated to readings, the reading questions, the class activities, and the concept exams, but also that success on the concept exams and final exam will be dependent on successful completion of the two former course components.

Figure 1. Engineering and Society Course structure

<table>
<tr><td colspan="2">FINAL EXAM (10%)
Cumulative, Reflective</td></tr>
<tr><td>DESIGN PROJECT (20 %)
75% "Team"; 25% "Individual"</td><td>CONCEPT QUIZZES & EXAMS (45%)
Points Summed Through Semester</td></tr>
<tr><td colspan="2">CLASS PARTICIPATION & ACTIVITIES (15%)
5pts – 20 pts; take-home & in-class; ALL components must be completed</td></tr>
<tr><td colspan="2">READINGS & JOURNAL = "Reading Questions" = "RQs" (10%)
"In-class" check + Collected and checked for "completion" at end of subtopic or topic</td></tr>
</table>

As most individual classes are designed to be a mix of discussion and class activities, it is essential that the students arrive prepared to participate. Therefore, both the reading questions and any preparation for class activities are checked for completion at the beginning of the class and then collected later for an assessment of the quality of the students' work. In order to encourage active learning and connection of ideas, the activities for each topic are designed to be open-ended but to use the reading questions as a foundation; they as an opportunity for the students both to practice and apply the material in the reading as well as an opportunity to engage more deeply with it; typically the application is to an emerging technology or current societal problem. In some cases, unique activities have been designed that encourage the students to actively engage with the content in the form of a role-based activity; for example an open-ended role-play was developed as a companion activity for the ethics topic and a "town-meeting" was designed as a companion to the topics of risk and public control of technology.[6] Most activities have three graded components: 1) completion of any preparation prior to class; 2) active participation in class; and 3) completion of a reflection question after the class activity. Frequently, activities are designed such that different groups of students can explore different perspectives or apply different concepts which are then brought together during the in-class portion of the activity, which enables the students to have the opportunity to solve problems in different ways as well as to compare and contrast the different solutions. Various activities such as those that precede the design project allow students to choose topics of interest to them.

The concept exams and quizzes are designed both to assess the students' understanding of the material and to allow them to continue to learn in the process of completing the assessment; the concept exams and quizzes differ only in scope with quizzes covering typically one chapter and exams covering two or more chapters. Both are designed as individual take-home assessments that are submitted both electronically to Moodle Turnitin and in printed form. This form of assessment meets the needs of modern students in terms of immediacy, frequency and lower value, and, with careful design, relevance. The concept exams and quizzes are designed to guide the student through an application of the key concepts to a problem that reflects a 'real-world' problem (e.g., emerging technology, recent accident, ethical dilemma). The take-home format better enables application and continued learning as well as providing a better format for ensuring relevance as outside topics and sources can be more easily included or referenced. The cumulative final exam addresses key topics developed over the semester, and, ideally, provides the students with an opportunity to reflect on the learning gained throughout the semester.

The objective of the design project is to allow the students to experience the engineering design process. The project is team-based and requires each team to design, build, test, and demonstrate a prototype design as well as to document the design process. The documentation includes three progress reports, a class presentation and demonstration of the prototype, and a written final report. Each student is required to keep an engineering logbook as well. The project grade is based 85% on the documentation of the design process and 15% on the performance of the prototype (performance specifications and design constraints are provided to each team as is the rubric that will be used to evaluate the performance). Each student completes a confidential peer evaluation of the team members at the end of the project. Individual student grades are a combination of the team grade (75%) and an individual grade based on the logbook (5%) and the confidential peer evaluations (20%). The design project task is necessarily simple as there is no lab component of the course and students complete the project primarily outside of class.

"Real-world" examples

As noted, one of the objectives of the course design is to enable first year engineering students to become engaged with the profession of engineering, so various assignments and class activities to meet this objective as well as encourage active learning. Three recent innovations serve well as examples:

1) Class Activity: Students learn about engineering as a profession through individual and group exploration of the various engineering disciplines (Box 1).
2) Design Project: Students are introduced to the design project via an exploration of the NAE Grand Challenges,[13] and the theme of the design project has been linked to a real-world engineering problem. (Box 2)
3) Ethics Topic: The approach to teaching ethics has been updated to encourage the students to actively participate in engineering decision-making by adding a role-play and shifting the coverage of the text materials to allow a more comprehensive approach to analyzing and solving ethical problems. In response to recent research, this approach is applied to both microethical and macroethical problems.[15]

Box 1: Real World Example #1 - Class Activities for topic "What is Engineering?"

Part 1: "Exploring Engineering Disciplines"

For the engineering discipline that you have chosen, please answer the following questions using the sources provided or of your own choice. Your answers do not need to be lengthy, but they will need to be specific and complete enough that you can complete the in-class activity..

i. State your engineering discipline.
ii. When did your engineering discipline first emerge?
iii. What societal need or adoption of a new technology led to this emergence?
iv. State what engineers in your discipline do. Has this changed much over time?
v. Using the indicated source to answer the following questions.
   - Source: "ASEE 2012 ASEE Profiles of Engineering and Engineering Technology Colleges"
   - http://www.asee.org/papers-and-publications/publications/11-47.pdf
   1. How many engineers were awarded undergraduate degree in 2012? What percent of total degrees is this?
   2. What percent of this total were men? Women?
   3. Some disciplines have a larger gender gap than others (~ 9% - ~ 40% women). At which point in this range is your discipline? Why do you think this is so?
vi. What is one major historical achievement for your discipline? (e.g. major technology adopted)
vii. What is one challenging area today that is important for your discipline? (e.g. new technology that is being developed)

Part 2: In-Class Activity - "Emergence Timeline" & "Compare and Contrast"

a. With a group of students who share the discipline that you chose, discuss your answers and update them if necessary to be sure they are complete.
b. Each "discipline" will share their results with the class as we complete an "emergence timeline" on the board and compare and contrast the various disciplines.
c. Take notes on two (2) ADDITIONAL disciplines; identify the disciplines.

Part 3: "Engineering Job Opening"

a. Identify a company and an employment opportunity for an engineer in one of the engineering disciplines; state them. Once you have identified the company and the position, answer the following:
b. Write a brief description of the position. (Cite your reference!)
c. Briefly describe what you think this job would be like. Consider some of the following questions as a general guide:
i. What do you think you would be doing?
ii. Where do you think you would be working? With whom would you be working?
iii. Do you think it would offer short- and/or long-term opportunities?
iv. Do you think it would be fun? Challenging? What parts of the job do you think you would like? Dislike? Why?

1) <u>Class Activity: "Exploring Engineering Disciplines"</u> - The coverage of the topic "What is engineering?" is designed to encourage the students to discover and explore the evolution of engineering and the emergence of the various engineering disciplines as a result of societal need or the invention and adoption of a new technology. Assigned on the first day of class, Part 1 of this activity (Box 1) is designed to facilitate a class discussion on the second day that allows the students to construct their own knowledge of the societal factors that caused the emergence of the engineering various engineering disciplines as well as the nature of these branches of engineering today; this is as opposed to relying solely upon the reading of the limited information in the text (this is especially appropriate as many students may not yet purchased the textbook). Part 2 of the activity provides the students with the opportunity first "to pair" and then "to share" information also sets the stage for the active class participation that is expected throughout the semester. Further, this assignment is both popular and relevant for the FYE students who are often still deciding on a specific engineering major. It also provides the NM students with initial exposure to the engineering profession. Part 3 of the activity allows the students to explore the nature of a real engineering job of their choice.

2) <u>Design Project: Introduction and Theme</u> - With the objective of exposing the students to societal needs that are challenging engineers today, the topic of engineering design is introduced with a class activity in which the students explore the NAE Grand Challenges.[13] The students actively experience the engineering design cycle through a simple team-based design project the theme of which is linked to a real-world engineering problem; several recent projects are listed in Box 2.

For example, the design project for Spring 2015 addresses the technology "plastics;" and the idea that though they play an ever-expanding role in our daily lives, there are significant negative effects on our health and our environment. Specifically, the students are tasked to explore the challenge of solving this problem with a focus on re-using or re-purposing plastics. The students are first tasked to perform background research on the problem and then to design, build, and test a prototype of a land-based vehicle that is suitable for transporting an individual from one place to another using primarily post-consumer plastic along with other recycled materials. The design is subject to both performance specifications (e.g., transportable to the test site, must move from

Box 2: Sample design projects linked to real-world engineering problems

In recent semesters, the simple design project has been linked to a real-world engineering problem. Further, <u>all projects</u> emphasize the use of recycled or repurposed materials for the design.

- Portable back-pack bridge (inspired by *Bridges to Prosperity* http://bridgestoprosperity.org/)
- Land-based vehicle build from recycled plastics
- Prosthetic arm (adapted from *Get a Grip!* Dr. Suzanne Olds, Northwestern University Biomedical Engineering Department and Dr. David Kanter of Northwestern's School of Education and Social Policy. http://www.bme.northwestern.edu/about/communityoutreach.html)
- Bench-scale wind turbine
- Bench-scale solar hot water heater

point A to point B, a distance of 10 feet, remaining intact throughout the process, and must transport an individual a distance of approximately 10 feet, remaining intact from beginning to end) and design constraints (e.g., materials, tools, cost ≤ $20 total). As noted, the bulk of student work on the design project is done outside of regular class periods. Note that the design project also serves as a platform for the students to consider the ethical impact of both microethical and macroethical decisions. For example, the design choices made (e.g., materials) must be considered with respect not only to factors such as safety and durability but also long-term impact of widespread the adoption of the product (e.g., effects on the environment, sustainability).

3) <u>Ethics – A comprehensive approach to ethical problem-solving and role-play</u> -

As ethics is one of the most challenging topics to address in such a way that the students can relate it to solving real-world engineering problems, an description of the teaching methods for this topic is presented here. In response to a review of the literature, the instructors have redesigned the curriculum in such a way that there is a blending of traditional and new approaches. First, as noted by Kroesen and van der Zwaag, many undergraduate engineering students lack extensive work experience and can find it difficult to imagine themselves in the role of decision-makers. In response, the team of instructors adapted a role-play in which the outcome is not known beforehand and introduced it to supplement the introductory chapter on ethics and the space shuttle *Challenger* case study in particular.[14] As designed, this open-ended role-play experience in which the roles are clearly defined and personalities described not only enables students to experience "live" decision making process, it also allows them to explore the effects of personality, relationships, and ambiguous data on decisions. The challenges faced during the "live" decision-making of the role play stands in stark contrast to the "hindsight is 20/20" perspective that seems to prevail when the students read the *Challenger* case study, though many of the influencing factors (e.g., economic, political, ambiguous data) are similar. Students who are not playing a role are assigned one of four types of observer roles (informative, normative, responsibility, and performance). In the subsequent class discussion students explore the impact of the various roles and the responsibilities associated with them, the use of information, the expression of norms and values, as well as aspects of the performance itself.

Second, recent research indicates that there may be superior approaches to teaching engineering ethics than the traditional approaches that include engineering codes of ethics and the application of moral theories; though these may have utility, some researchers are skeptical.[15] According to Herkert, Davis (1999a)[16] notes that case study methods do encourage students to express ethical opinions, to identify ethical issues, and formulate and justify decisions, as well as encouraging the "develop[ment] in students [of] a sense of the practical context. More recently, researchers such as Whitbeck (1998; as cited by Herkert) [17] argue that the problem-solving approach used in engineering design is a useful paradigm for solving ethical problem. Finally, Herkert proposed that the ideal solution may be a curriculum model that would simultaneously address: (1) professional and ethical responsibility and (2) the societal context of engineering; this would facilitate a shift from a focus on microethical problems (i.e., the dilemmas confronting individuals) to an emphasis on the macroethical issues related to the nature and development of technology.[15] As the complex relationship between technology and society is a main theme of the course, the understanding of the decision-making associated with macroethical issues is of particular importance.

In response, while the instructors continue to address content such as engineering as a profession, the importance of engineering codes of ethics as a reflection of social responsibility and their application as a tool for guiding decisions, and the application of ethical theories, the emphasis has shifted to enable the students to apply the various ethical problem solving techniques in a more comprehensive manner than they are presented in the text as well as to apply them to macroethical problems. It is not until the *fourth chapter* of the text on ethics that the author states that the *first step* in solving any ethical problem is to completely identify and clarify the three categories of issues (factual, conceptual, and moral) involved in the problem; this often puts the problem in the proper framework and often helps point to an ethical solution. Further, once this is accomplished, he notes that three choices are possible, "the higher value", the "creative middle way", and "the hard choice."[8] The instructors now introduce these tools at the very beginning of the topic, along with a discussion of values, norms, and the potential for conflicting values. Likewise, the concept of an ethical dilemma as an inequitable distribution of benefits and costs/risks is introduced, and for each problem and case study, students identify key stakeholders as well as the expected benefit or risk/cost that will accrue to each. These tools then serve as the framework for all of the problems and case studies that are explored throughout the topic.

For example, the space shuttle *Challenger* is the first case study presented in the text and the emphasis is on answering specific questions on incomplete test data and informed consent. In contrast, the application of the comprehensive approach enables the students to analyze the case in a broader manner. They identify a broad array of facts (performance specification vs. actual test data, civilian teacher aboard, VP Bush in attendance) as well as the key stakeholders, benefits, and costs/risks. Thus, the incomplete data emerges as a factual issue that needs clarification, and informed consent emerges as a concept which may be used to clarify the ethical problem. Similarly, a discussion of the different ways the incomplete data can be interpreted can be extended to a discussion of the conflicting values demonstrated by each individual's behavior. Using the author's classification, the decision not to launch is choosing the higher value of safety, seeking a postponement until later in the day might be the creative middle way, and the decision to launch represents the difficult choices that must sometimes be made 'in the real world' when there are nontechnical factors as well as lack of complete information. Finally, the students seek to "solve" the ethical problem. For example, for the *Challenger*, students identify that the test data on the O-rings is ambiguous (i.e., a factual issue) and, if further data were to be collected, the decision becomes clear-cut. After identifying informed consent as a relevant concept, the students can see that an alternative solution would be to seek informed consent from the principle stakeholders such as the shuttle crew, President Reagan, and V.P. Bush. If these stakeholders have the information necessary for them to understand what is at risk and agree to the launch, than the decision to launch can be viewed as more fair. Thus, even when analyzing historical cases, the students are provided with an opportunity to identify factual, conceptual, and moral issues, which if clarified, would have resolved the ethical dilemma and enabled the identification of a fair, ethical decision.

As additional tools are introduced in successive chapters (e.g., the hierarchical nature of codes of ethics and ethical theories) they are merged into this framework. For example, the Union Carbide, Bhopal, India case study is introduced in the text in the context of applying ethical theories to specific engineering decisions (e.g., location of plant, lack of an evacuation plan). With the revised approach, the students first outline the entire case using the framework above. They identify stakeholders as well as the potential benefits and/or costs and risks that each would reap or bear if the plant were to be built. They identify facts which need to be clarified (e.g., are the chemicals to be used or produced at the plant harmful?), applicable concepts (e.g., informed consent, eminent domain), as well as conflicting values (e.g., the desire to experience economic development vs. ensuring the safety of the public). The students are guided to use this information to identify and clearly state the ethical dilemma (i.e., inequitable distribution of benefits and costs/risks). Then, instead of viewing the problem from a single perspective and applying an ethical theory demonstrating that the building of the plant is either ethical or unethical, the students are asked to apply at least one theory in order to demonstrate the perspective that building the plant is ethical and to choose a different theory to demonstrate the opposite. As a reflection, the students are asked to explain the value to a decision-maker of utilizing multiple ethical theories when analyzing an ethical problem. In conclusion, the students are asked to identify a fair or ethical solution, and, in the process, explain how they might resolve any factual, conceptual, or moral issues they identified earlier. Thus, as suggested by Herkert, this approach facilitates a shift from a focus on microethical problems (i.e., the dilemmas confronting individuals) to an emphasis on the macroethical issues related to the nature and development of technology.[15] These class activities lay the foundation for the students to analyze and identify potential ethical solutions for other large-scale engineering projects on the concept exam that assesses this material.

In class discussions and activities, various technology-based projects are explored with this method (e.g., local wind farms or nuclear power plants) and the associated concept exam parallels the class examples. For example, in Fall 14 students analyzed the decision to build the St. Lawrence Seaway; a summary is shown in Box 3. It is the intent of the instructors to maintain the structure of the coverage of this topic each semester, but to address different problems on successive concept exams; in Spring 15 students will analyze the Keystone XL pipeline. In all cases, students are provided with specific source material on the project to use to perform the analysis. This approach to the topic of ethics allows the topics of professional and ethical responsibility to be addressed simultaneously with the societal context of engineering; the “feat” of technological advancement, especially modern, complex, unpredictable technologies, is not separated from the overarching impacts - both positive and negative, both intended and untended - on society. With this approach to the topic of ethics, the students are given a unique opportunity to experience engineering decision-making in the context of solving ethical problems that reflect the nature of real-world engineering problems. As noted in the *Challenger* case study, as engineers advance in their careers, the decisions they must make go beyond the decisions associated with design choices to the realm of project management; thus, students should be exposed not only to system engineer level decisions but also to engineering management decisions. The students are encouraged throughout the rest of the course to consider through a lens that focuses on the responsibility that comes with the implicit contract that engineers have with society.

Box 3: Ethics concept exam “St. Lawrence Seaway” summary
The students were tasked to review the background material on the St. Lawrence Seaway and asked to evaluate whether the building of the Seaway would be ethical or unethical using the comprehensive method applied during class activities. In particular, this problem encouraged the students to explore the benefits that would accrue to numerous communities by enabling increased transportation of goods as compared with the costs/risks that would be assumed by those who would be displaced by the project. One concept identified by the students that needed clarification was that of the seizing or destruction of property (including negative impacts on the environment). Following the application of the ethical theories to the problem, the students were asked to identify a fair or ethical solution, which may have differed from the actual solution. One solution proposed was not only to offer compensation to those who were affected but also to attempt to gain acceptance from these individuals first (i.e., “informed consent”) rather than to seize property by eminent domain.

Assessment of Learning Outcomes and Course Impact on Student Success Rates

The new course has evolved to become a key component of a more flexible first-year engineering curriculum designed to increase the chances of success for all FYE students in all first year courses, and preliminary analysis indicates that these curricular changes have been effective. The effectiveness of the course and the teaching methods has been evaluated both by conducting an assessment of the student learning outcomes and reviewing and analyzing selected results from a student attitude survey that is administered both at the beginning (pre-) and the end (post) of the semester. Student learning outcomes have been assessed using the design project deliverables and both individual exam questions and concept exams aimed at specific outcomes. Recent direct assessment of course learning outcomes indicate that expectations for student learning are being met or exceeded for course components aimed at ABET General Criteria 3(c), (f), and (h).[18] Throughout this time period, various internal data has been collected and analyzed to evaluate the effectiveness of the curricular changes that indicates an improvement in student performance in the first year mathematics and science courses. Further, initial results from student attitude surveys designed for use with this course (pre/post) show statistically significant gains in categories of: understanding the nature of engineering, fit with the engineering profession, and self confidence in problem solving and teamwork; preliminary results were presented.[1,18] A preliminary review of selected quantitative and qualitative responses in the survey indicate that the students are responding positively to the course structure as well as achieving the desired course outcomes of engaging in engineering and gaining an understanding of the complex interrelationships among engineering, technology, and society.

Outcomes assessment

The course primarily addresses ABET criteria (c), (d), (f), (g), (h), and (j). Direct assessment of selected learning outcomes has been conducted using design project deliverables, concept exams, and specific exam questions aimed at the particular outcomes, ABET General Criteria 3(c), (f) and (h), which are emphasized in the course. [19-20] Scoring rubrics were used for the design projects and specific criteria were used to grade the exam questions.

Recent data demonstrates that the students are not only meeting expectations for these key outcomes but also, by extension, for the course. The questions used for assessment in Spring 2014 were very similar to those used in Fall 2013. These questions served as the basis for the more frequent, more focused concept exams used in Fall 2014 and Spring 2015. For the Spring 2014 semester ABET 3(c), Design, 37.7% of the students exceeded expectations; 57.2% met the expectations, and 5.1% evidenced a need for improvement. For ABET 3(f) – Ethics, 44.3% exceeded expectations, 45.0% met expectation, and 10.7% evidenced a need for improvement. Finally, for ABET 3(h) – Societal Context, 34.3% exceeded expectations, 52.1% met expectations, and 13.6% evidenced a need for improvement. These results are similar to those in the other semesters. Over time, the assessment focus has remained the same; specific exam questions and rubrics are available on request.

Impact on success in other courses

A primary goal of the curriculum modernization, in particular the decoupling of the first physics course from the first calculus course, was to provide all students with increased opportunity for academic success and thus improve FYE student retention in the engineering programs. Thus, the overall success rate for students in each of the FYE courses (i.e., the first and second calculus courses, first and second physics courses, and the first and second chemistry courses,) has been tracked for the years 2011 - 2014. Prior to the curriculum changes, the overall success rate for the first physics course in the fall semester was 78.5% and the rate of success for students who would have been identified for delayed physics was much lower at 57.9%. Following the curriculum change, the success rates (C grade or better) for the first physics course for the delayed students increased to 81.3%, 71.3%, and 89.0% for Spring 2012, 2013, and 2014, respectively; this is viewed as a significant improvement. This resulted in an improvement in the overall success rate from 78.5% to 87.6%. Recently, the success rate in Physics II for the students who delayed Physics I has increased to 88.3% and 74.2% for Fall 2012 and Fall 2013, respectively; the historical success rate for this cohort of students was only 65.7%

Though details are not presented here, analysis indicates an overall improvement in success in both the first calculus course and the first chemistry course in the fall semester. In calculus, there seems to be improvement in success from approximately 70% overall to approximately 80% overall. In chemistry, the overall success rate has increased from approximately 77.5% to just over 81%. In contrast to the gains discussed for the first physics course in the spring semesters, where the improvement might be attributed to improved mathematics preparation for the delayed group, the gains in both calculus and chemistry in the Fall might be attributable to decreasing the stress level associated with co-enrollment in both calculus and physics.

The improvements in the success rates for the delayed students in the physics sequence of courses as well as the other first-year courses indicate that the curriculum modernization, especially in combination with other retention initiatives, has been an effective strategy. Longer term analysis will need to be conducted to better understand the impacts as the number of students has identified to delay the first physics course has increased from 190 in Fall 2012 to 251 in Fall 2014 and the new course has been made required.

Course effectiveness: Student Attitude Survey Ranking and Free Responses

Student Attitude Survey – Description

From the course inception, it was deemed desirable to be able to perform some measure of the course impact on the students' perception of and engagement of the engineering profession as well as both their level of interest and expectation for success in completing their engineering degree. A survey was developed in 2011 as part of a study to measure these outcome by using a single-group pre-test/post-test design with the pretest acting as the control group and has been administered in each successive semester on a voluntary basis to all students enrolled in the course.[21] Though a summary is provided here, a description of the study, including details of the survey, as well as preliminary results were previously published.[1,18]

In general, the study is designed to measure the role of the course in clarifying the students' perceptions of the broad or holistic nature of engineering problem solving and design, and in fact, of engineering careers in general, as well as to positively impact their attitudes toward studies and careers in engineering. Students are asked to complete anonymous, IRB (University Institutional Review Board) approved questionnaires during the first week of class, and again near the end of the semester; "pre-" and "post-responses" are matched and tracked. Though the questionnaire was developed as part of this project; most of the attitude items were adapted from existing instruments,[*] while original items were created to measure course objectives related to students' understanding of the breadth of engineering and interactions with society. The

[*] Existing instruments include (TUAN & ROSENBERG);[22-23] as well as the APPLES (Academic Pathways of People Learning Engineering Survey), created by the CAEE (Center for the Advancement of Engineering Education) project and available online at http://caee-aps.stanford.edu/phpESP/admin/manage.php; and the LAESE (Longitudinal Assessment of Engineering Self-Efficacy) survey versions 3.0 (copyright 2006) and 3.1 (copyright 2007), which are products of AWE (Assessing Women and Men in Engineering), available online at www.aweonline.org.

questionnaire contains 27 items that use a Likert-type format with five options ranging from strongly disagree (1) to strongly agree (5). The first 13 items are intended for all students (ALL), followed by nine items intended for 1stYE and five items for NM students. *Though in depth discussion of the results of this study is beyond the scope of this paper, there is an ongoing parallel effort to analyze the quantitative data that has been collected.*

Prior to the Spring 2013 semester, the student attitude survey was updated to enable the students to provide direct feedback to the instructors on the course format; it is this direct feedback that is referenced primarily in this paper. Specifically, three questions were added that prompt the students to "use the numbers 1 (BEST), 2 (MIDDLE), 3 (WORST), to rank the following 3 types of classroom environments to show your preferred experience in a college classroom. Each choice should be a unique number: 1, 2, 3. rank from 1 (best) to 3 (least) the course components of activities, discussion, and lecture." In addition, three free response questions were included that prompt the students to describe (a) one (1) thing that you liked BEST about this course; (b) one (1) thing that you would CHANGE to make this course BETTER; and (c) which aspects of this course have been most valuable to you.

A summary of the rankings for class format for Spring 2013 and Fall 2014 is shown in Table 3. For Spring 2013, the responses (Sample size =97) indicate that the students prefer activities, discussion, and/or a combination of them over lecture. As noted earlier, frequently the activities have both a "preparation" component and an "in-class sharing" component, and the sharing component, especially any compiled group responses, is often blended with the class discussion. Similarly, the activity may be used as a guide to class discussion.

Table 3. Student attitude survey ranking (Spring 2013, Fall 2014)

Spring 2013	**Activities**	**Discussion**	**Lecture**
1 = "BEST"	**45**	40	22
2 = "MIDDLE"	32	44	19
3 = "WORST"	20	13	55
Total:	**97**	**97**	**96**
Fall 2014			
1 = "BEST"	**94**	42	34
2 = "MIDDLE"	45	88	37
3 = "WORST"	31	40	99
Total:	**170**	**170**	**170**

A similar analysis was conducted for the Fall 2014 semester in which the instructors introduced some restructured and several new activities designed to allow the students to apply the concepts from the reading questions and intended as practice for the concept exams. The responses (sample size = 170) indicate that class activities are even more strongly preferred (94) than they were, and the smallest number of students preferred lectures (34).

The free responses (Sample Size = 170) also were reviewed for primary content referring specifically to the three ranked class formats (i.e., "Activities," "Discussion," and "Lectures") as well as specific references to the class components of "Role Play," "Design" (e.g., project, process), "Engineering," "Society," "Ethics," "decision" (or decision-making), "Exams," and "Reading" or "Reading Questions;" As shown in Table 4, the specific references to "Activities," "Discussion," and "Lecture" as "BEST" at 21, 13, and 3, respectively, are consistent with the ranking results. A large number of students (27) identify the "Design" experience as the "BEST" part of the course; three students specifically identify an aspect of working on a team as "BEST." Of primary interest are the frequent references to "Design," "Engineering," and "Society" among the "BEST" responses. The most frequent "CHANGE" responses indicate a preference for more activities and discussion and less lecture.

Table 4. Survey "Free Response" summary

Class Component	**"BEST"**	**"MOST VALUABLE"**
Activities	21	6
Role play	4	-
Discussion	13	7
Lecture	3	5
Design (project, process)	**27**	**33**
Team/Teamwork	**3**	**16**
Engineering	**17**	**66**
Society	**3**	**24**
Ethics	**3**	**21**
Decision-making	3	5
Exams	5	3
Reading/Reading Questions	5	15

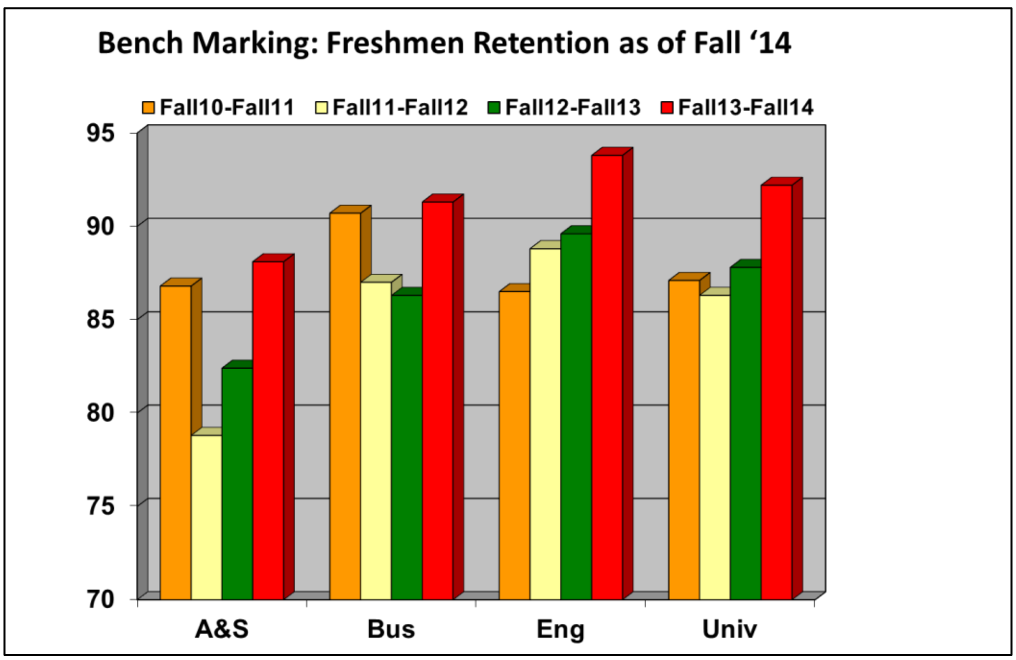
Many students identify the design project (33) and/or working on a team (16) as "MOST VALUABLE." While not assessed specifically, this provides support that the course also is meeting the objectives of ABET (3) d. "Ability to function on multidisciplinary teams." The large number of specific references to "Engineering" (66), "Society" (24), and "Ethics" (21) as "MOST VALUABLE" indicates that the course is meeting the defined objectives. These numerous responses can be interpreted as indicating that the course is enhancing the engagement of both first-year engineering students and non-majors with the field of engineering in general.

A closer reading of the student responses indicate that FYE students are gaining an understanding the nature of engineering and engineering decisions, are feeling confident of their fit with the engineering profession, as well as gaining self confidence in problem solving and teamwork. For example, one student noted, "*I absolutely enjoy [the course] because it is a class that requires you to not only think about issues and topics thoroughly, it requires you to think as if you were already an engineer. It dispels the notion that engineers are purely technical people and this is an important aspect for engineers to be to know*." More specifically, the responses indicate that students are gaining an understanding of the complex relationships between engineering and society as well as developing an appreciation for the need for engineers to be able to solve ethical problems as well as technical problems. For example, one student noted as most valuable, "*Learning how to apply ethics to engineering problems and following the engineering design process*." Further, several student responses also indicate that the approach to the course is enabling students to develop learning skills that will prove valuable throughout their academic and professional careers. For example, one student notes, "*learning about engineering in general and what the job will be like and what types of problems and people I may encounter gave me a better idea of engineering as a career*." Another response in particular stands out, "*I think the course overall was valuable because it teaches you that as you become an engineer you will not just be developing products but also playing a role in society development. It helps show that you have a responsibility to society as an engineer to create products that will not only be beneficial but also be safe*."

FYE Retention 2010-2014

It is important to note that the implementation of the revised curriculum occurred concurrently with the launch in 2009 of a University Retention Initiative that addressed all aspects of the retention of students from the first to second year. Further, the specific efforts described in this paper are focused on retaining students in the engineering programs, though this is linked to the ultimate objective of retaining students at the university even if in a different academic program. Retention data gathered during the years that these curricular changes were being made indicates that these changes have contributed to increased retention through the first two years of the engineering program; this data is summarized in Figure 2.

Figure 2. FYE Retention Fall 2010 – Fall 2014



While there are multiple factors that affect overall retention in any program, any school, and any university, including total enrollment over time, the retention data show a large increase in the retention rate for FYE students from 86.5% in 2010/11 to 93.8% in 2013/2014. It is viewed as an extremely positive indicator that in 2013/14, the retention rate for FYE students actually exceeded that of not only the other two schools (i.e., Arts & Sciences and Business) but also the overall university retention rate of 92.2%. The administration is confident that the changes made, including the modernization of the first-year curriculum, have contributed to these improvements, though it may be impossible as well as beyond the scope of this paper to trace them specifically.

Conclusions and Future work

The FYE curriculum has been modernized by creating a more flexible curriculum that includes a new engineering and society course emphasizing the complex relationships between engineering, technology, and society and which included a simple design project that is linked to a current engineering challenge. In the context of "engagement" as much as "retention," significant changes have been made to the course curriculum to increase the active learning opportunities offered to the students as well as to link the various elements of the course (e.g., class activities, team-based design project, and summative assessments) to the engineering challenges facing engineers and society today. The new course was successfully piloted, rolled-out for multiple sections, and has been made a required part of the FYE curriculum. The course is designed to:

1. Exposes students to the engineering design process with a hands-on component;
2. Addresses the needs of both first-year engineering students and non-majors; and
3. Positively affects students' confidence in approaching design problems/new problems or challenges, students' perceptions of their understanding of the broad nature of engineering, and non-majors' perceptions' of their "fit" with the engineering profession; the latter is demonstrated by student responses such as, "*I believe the overall exposure to the different aspects of engineering has been most beneficial. It has made me realize that this is the major I want to remain in*."

The team of instructors has maintained extremely close coordination across six to eight sections of the course, including common reading assignments and reading questions, common class activities (though not all instructors complete all activities each semester; there is flexibility in the coverage of the course content), as well as common concept exams and final exam. At the same time, significant progress has been made in making the course learner centered, and possible future efforts will address a shift to a flipped classroom. The course is currently taught in a typical format of either two or three times a week; an alternative to be explored especially in the context of 'flipping' the classroom would be to offer a trial section taught offered once a week in a three hour block.

While the recent focus on linking the reading material to "real-world" problems is effective, future efforts could move away from the current reading, "*Beyond Engineering*" in particular as it is getting older, and a shift made towards alternative readings. An alternate approach would be to compile a selection of primary sources that address the course content. Further, rather than achieving the course content though the linking of readings to a variety of contemporary issues, there could be a sustained focus on a significant contemporary issue. In fact, there has been a shift in this direction as the instructors often use a particular technology theme (e.g., autonomous vehicles) and link it to various class topics and activities throughout the semester. This would require an appropriate selection/ provision of texts, online resources, etc., that would provide the basis for exploration of the important concepts and issues. Depending on instructor orientation, use of appropriately selected fiction as the basis for reading and reflection can be envisioned as well. In short, the concept of combining design process immersion with engineering and society concepts and outcomes could be achieved in a variety of ways.

Future work will continue to include both the qualitative and quantitative analysis of the various data collected using the Student Attitude Survey. Similarly, long-term impacts on student success in the first year and beyond will continue to be evaluated.

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