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Growth of Student Awareness within a Discipline-Agnostic Introduction-to-Engineering Course

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Abstract

As described in this Complete Paper, an introduction-to-engineering course, to be taken in the first semester by all entering freshmen, is created. Its highest objectives are for the students to become maximally aware of the different engineering disciplines which may be studied at their institution and for each student to develop a deeper appreciation of his/her chosen discipline. The semester is split into three modules and the population of students is split into three groups. Each module contains discipline-specific material to highlight each major as well as discipline-agnostic material which introduces the knowledge and skills which are expected of all engineers. The instructors teach each group of students in each module for approximately one-third of the semester, and afterwards the students rotate to a new classroom with a new instructor. After each module, the students were surveyed regarding their familiarity with the different engineering disciplines and their confidence in having chosen engineering as their field of study. Results indicate that, across the semester, students' confidence in having chosen a technical field remains high and students' familiarity with disciplines outside their chosen major grows.

Keywords

first-semester, first-year, freshman, introduction, multidisciplinary

Motivations for This Work

Selecting a major strongly tied to one's interests and talents is a challenging task for many college students. For freshmen engineering majors, deciding a particular discipline on which to focus is sometimes confusing and intimidating. Unfortunately, it is common for a student to select a discipline based on limited or inaccurate information, to have a shallow understanding of that discipline or to feel little enthusiasm towards it, and to turn away from that discipline when the difficulty of required coursework ramps up in later semesters.

The authors of this paper want for their students to love what they do -- to be well-informed about their chosen profession and to use their enthusiasm for it as a well-spring of motivation, especially when their upper-division courses give them trouble. Towards that end, the authors have designed an *Introduction to Engineering* course, required of all engineering freshmen entering the authors' institution, which presents to the students all engineering opportunities available at their school. The role of the engineer in society is defined and an overview of each discipline is presented. Since this course is delivered in the first semester, students (if they so desire) can change majors while maintaining their timeline for graduation.

This paper presents the structure of the *Introduction to Engineering* course. Three sections are taught by faculty from each of three departments: Civil and Construction Engineering, Electrical and Computer Engineering, and Mechanical Engineering. The three sections of students are a mixed population representing all engineering majors. The 15 weeks of the semester are split into three modules, and instructors move round-robin through each of the three sections. Major topics include (a) adoption of best practices for success in college and for studying engineering specifically, (b) examination of each sub-discipline within each major, and (c) cultivation of skills required to be successful as a practicing engineer.

After each of their three modules, students were surveyed regarding their understanding of their chosen discipline, their awareness of adjacent disciplines, their confidence in their selection of a technical major, and their enthusiasm for their chosen discipline. The evolution of the student's attitudes across the semester indicates that exposure to a range of instructor and student perspectives in the common-enrollment *Intro* course generates greater interdisciplinary awareness. Seeing students more knowledgably committed to their engineering discipline, the authors anticipate greater student satisfaction and retention in their majors.

Developing Objectives for our Intro-to-Engineering Course

As of Fall 2024, all engineering freshmen at the authors' institution, regardless of their declared discipline, will enroll in a section of *Introduction to Engineering*. This discipline-agnostic course replaces the discipline-specific courses (e.g. *Intro to Civil Engineering*, *Intro to Mechanical Engineering*) which have been a mainstay of the freshman curricula for years. The authors piloted their broader *Introduction to Engineering* course during the Fall 2023 semester; a subset of freshmen from each of five disciplines -- civil engineering, computer engineering, construction engineering, electrical engineering, and mechanical engineering -- was enrolled. The data reported in this paper originates from this subset/pilot group.

Before offering the pooled *Intro* course, the authors conducted an extensive literature review of introduction-to-engineering courses and unified-first-year engineering programs [1]. From their review, the authors adopted several key ideas:

- The *Intro* course must address professionalism, computer-based calculations, and design [2]. The students should be able to perform rudimentary analyses, represent data graphically, construct prototypes, and evaluate their solutions [3].
- Most entering freshmen are unaware of their career opportunities; thus, the course should expose students to engineering-related career paths [4] including research [5].
- To hold students' attention, traditional (full-period) class lectures should be replaced by shorter, content-focused presentations followed by interactive activities [6]. To introduce discipline-specific tools while keeping the experience "fresh" for students, faculty are encouraged to rotate teaching different groups of students.
- Graded exercises may consist of individual written homework assignments and quizzes, while traditional written exams should be avoided. Team-based projects [7] are highly encouraged, especially those which are multi-disciplinary [8].
- Many entering freshmen are unprepared for rigorous academic study; thus, the *Intro* course should address how to be successful in college [9]. Beyond academic preparedness, retention is improved by generating enthusiasm for engineering [10] and by fostering a sense of community amongst students [11].

A popular idea at many universities is the integrated curriculum -- common objectives and assignments overlapped with non-engineering courses that students take at the same time as their engineering courses. One school paired three engineering faculty with three English-composition faculty to develop linked engineering and writing classes; they emphasized analyzing data and tailoring communications to a particular audience [12]. Another school integrated chemistry, mathematics, engineering, and physics [13]. They maintained a cohort of students throughout all four courses, students worked in the same teams of four in all of their classes, they quickly became friends and formed study groups, and retention was improved compared to traditional (non-cohort, randomized) students.

Several engineering programs have incorporated service learning into their courses, to emphasize that the engineer's role in society is to solve problems in the service of humanity [14, 15]. Some colleges have partnered with local non-profit organizations [16] or local high schools [17]. Ambitious institutions have developed assistive technologies [18], constructed low-cost greenhouses [19], and designed affordable (sustainable, aesthetically-pleasing, functional) housing [20]. One program created learning communities: cohorts of students that attended the same classes, lived in the same dormitories, and participated in the same service-learning activities [21]. By practicing engineering *outside* of the classroom -- by solving problems for real people -- students learn to weight constraints, evaluate feasibility, develop specifications, and prototype solutions which are very practical. Also, there are few other educational experiences which foster such a deep sense of purpose and such a high degree of fellowship amongst students and local residents.

On campus, *inside* the classroom, a sense of community amongst students may be cultivated with team-based projects. Such projects can be discipline-specific and simple enough to be tackled by a team of incoming freshmen on their own [22], or projects can be multi-disciplinary and carefully structured to guide students to a functional design [23]. A unique format brings together different class years: all students (freshmen through seniors) register for a 1-credit-hour course and work on a design project for about 6 weeks, on teams containing a mix of class years [24]. In all cases, by working on projects that have more than one possible solution, freshmen understand that (a) real-world problems are open-ended, and (b) transfer of knowledge is quicker between people who must teach each other while working towards a common goal.

While the authors have not yet integrated their *Intro* course with non-engineering courses nor implemented service-learning as a central objective, they have adopted many practices recommended by faculty at peer institutions [2–11]. Survey results reported later in this paper indicate that, across the semester, students' awareness of different disciplines has grown as a result of how their *Intro* course was delivered.

Structure of our Intro-to-Engineering Course

The description of the authors' *Introduction to Engineering* course, as currently printed in the course catalog at the authors' institution, is given in Fig. 1. At the highest level, the *Intro* course exposes incoming students to engineering as a profession, provides students with an overview of skills required to be successful in college and as a practicing engineer, and briefly acquaints students with particular disciplines. These aims were broken out into the 8 overarching course objectives listed in Fig. 2.

Many class sessions tie the daily objectives to engineering design as an iterative process. The authors placed special emphasis on learning and levels-of-cognition (e.g. Bloom's Taxonomy), and they were unafraid to assign their students some unusual readings and engage them in open-ended discussions about the role of engineering in society [25].

"Required of Civil, Computer, Construction, Electrical, and Mechanical Engineering freshmen.
"Engineering students will broaden their understanding of the various engineering disciplines and subdisciplines and develop a greater commitment to one engineering major. Various projects, conducted within a collaborative learning environment, focus on creative engineering solutions through technical analysis, critical thinking, teamwork, communication skills, and professionalism. Students will explore practical problem solving, career paths, ethical canons, professional licensure, and other topics key to academic success.
"Laboratory: three hours"

Figure 1. Course description for *Introduction to Engineering*.

1. Describe and illustrate formative content, comparative analysis, design outcomes, design cycle, societal impacts, and career opportunities for engineering and each of the disciplines and subdisciplines. (B1)
2. Describe the ethics of the engineering profession. (B1)
3. Evaluate team performance using project management, leadership, and team dynamics concepts. (B5)
4. Describe the learning process and the learning resources available to the student. (B1)
5. Demonstrate self-directed lifelong learning through reading, interpretation, and synthesis. (B3)
6. Articulate the requirements for professional licensure and success in a future career. (B2)
7. Practice sustainable engineering problem solving techniques, engineering analysis and design processes. (B3)
8. Communicate ideas, engineered solutions, and designs using technical communication skills including oral presentations, written reports, and graphics. (B3)

Figure 2. Course objectives for *Introduction to Engineering*. Each objective is paired with its level along Bloom's Taxonomy (in parentheses).

The authors' pilot version of *Introduction to Engineering* was organized into three sections:

- 01 – 15 students – 4 Civil, 2 Construction, 0 Computer, 5 Electrical, 4 Mechanical
- 02 – 16 students – 6 Civil, 0 Construction, 1 Computer, 5 Electrical, 4 Mechanical
- 03 – 15 students – 3 Civil, 3 Construction, 0 Computer, 5 Electrical, 4 Mechanical

Each class met on Mondays & Wednesdays & Fridays, for 50 minutes per session. All sections met in a large tiered lecture hall for the first 2 class sessions and for the last 3 class sessions. In-between, each class was taught by 1 of the 3 instructors for 12 sessions, i.e. 4 weeks. After each 4-week module, the students rotated to a new room with a new instructor. Across all 3 rotations, all of the instructors taught all of the students.

The civil/construction professor taught his module in the tiered lecture hall, the electrical/computer professor taught his module in a computer lab, and the mechanical professor taught his module in a traditional classroom. To fill out each 4-week module, the authors divided between them discussions of skills relevant to *all* engineering majors and each professor selected an additional set of topics specific to his discipline to present:

- Mechanical Engineering topics + measurement, estimation, teamwork, and technical communication
- Civil & Construction Engineering topics + ethics, licensure, and learning practices
- Electrical & Computer Engineering topics + education, accreditation, data presentation, and solution preparation

Fig. 3 contains a set of screenshots from the authors' websites. Depicted here are the three 4-week modules broken out by each faculty member's discipline, plus a set of Field Reports assigned across the entire semester. The Field Reports are homework assignments, in the spirit of a "scavenger hunt," which require the students to find (and lightly use) the academic resources available to them. The authors believe that their students are more likely to request help (e.g. from a math tutor, if they need one for a later semester of calculus) if they already know that such help exists and they already know where to find it.

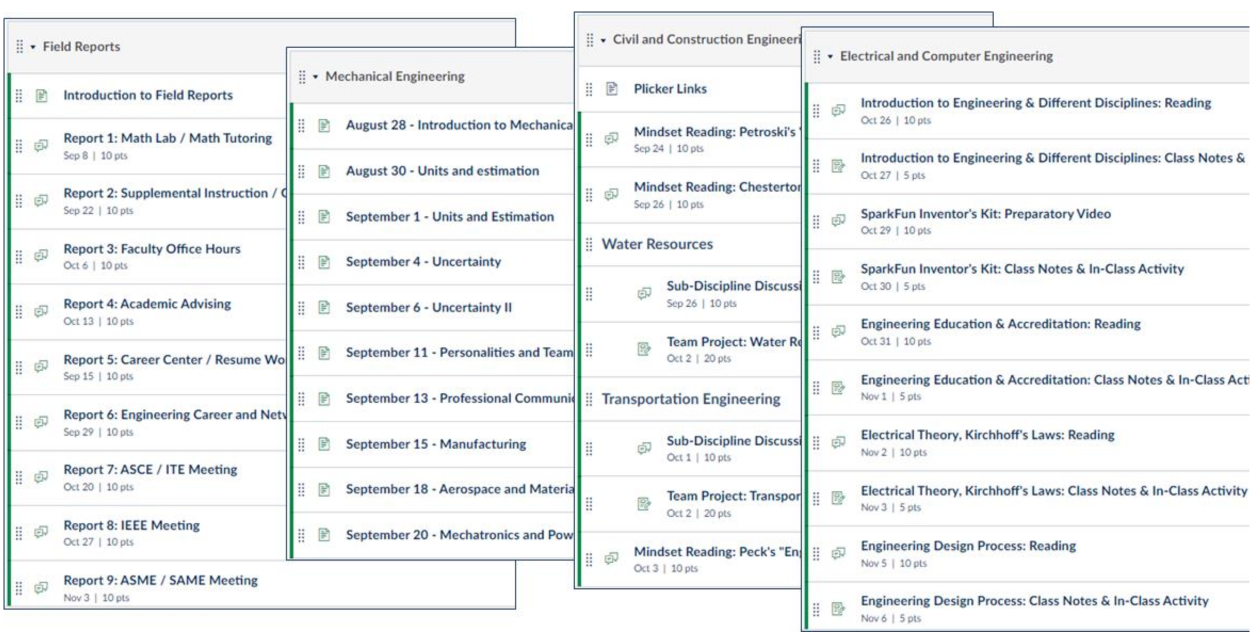

Figure 3. Screenshots of the course websites for *Introduction to Engineering*: Field Reports for all disciplines, plus 3 discipline-specific (4-week) modules.

The breakdown of grading for the *Introduction to Engineering* course is shown in Fig. 4. Each 4-week module (including discipline-specific and discipline-agnostic activities) is afforded 25% of the grade; the Field Reports account for 10%, and the Interdisciplinary Assignments (including the end-of-semester project) make up the remaining 15%.

Expected Performance Criteria	% of Grade
Interdisciplinary Assignments	15%
Field Reports	10%
Civil and Construction Module	25%
Electrical and Computer Module	25%
Mechanical Module	25%
Total	100%

Figure 4. Weighting of assignments for the *Introduction to Engineering* course grade.

At the first two class sessions, with all students gathered in the lecture hall, the authors introduced themselves and explained the purpose of the course: for the students to learn about different engineering disciplines, and for each of them to develop a deeper appreciation for their chosen major. A guest speaker from the on-campus Student Success Center made the students aware of academic resources available to them (e.g. tutoring). A guest speaker from the Career Center discussed the structure of a resume, the advantages of (summer) internships, and other useful strategies for transitioning to the professional world.

During each of the 4-week modules, most classes consisted of instructor-led discussions punctuated by hands-on activities -- often team-based exercises. For one activity during the Civil and Construction Engineering rotation, teams of students designed and built a water filtration system. A water bottle funnel served as the container; the filter itself could include sand, gravel, charcoal, rubber bands, and one coffee filter. During the Mechanical Engineering module, teams of students estimated the inner perimeter of a particular floor of their classroom building. They were *not* allowed to use standard measurement equipment (e.g. rulers, tape-measures) but they *were* allowed to use pieces of string (cut to any length, but without measuring them with a ruler). During the Electrical and Computer Engineering rotation, students learned basic soldering techniques; they populated the electronic components atop a circuit board for a video-game controller and display. Pictures of the soldering activity are given in Fig. 5.

For the final 3 class periods at the end of the semester (+ the 3-hour final exam session), all 3 sections of the class met again as a unified group in the lecture hall. The class was divided into teams of 3-4 students, and each team contained a mix of engineering majors. The teams worked on a unique design project whose (complete) solution required a multi-disciplinary approach. The summary-slide shown to the students, which encapsulates the objective of the project, is reproduced in Fig. 6.

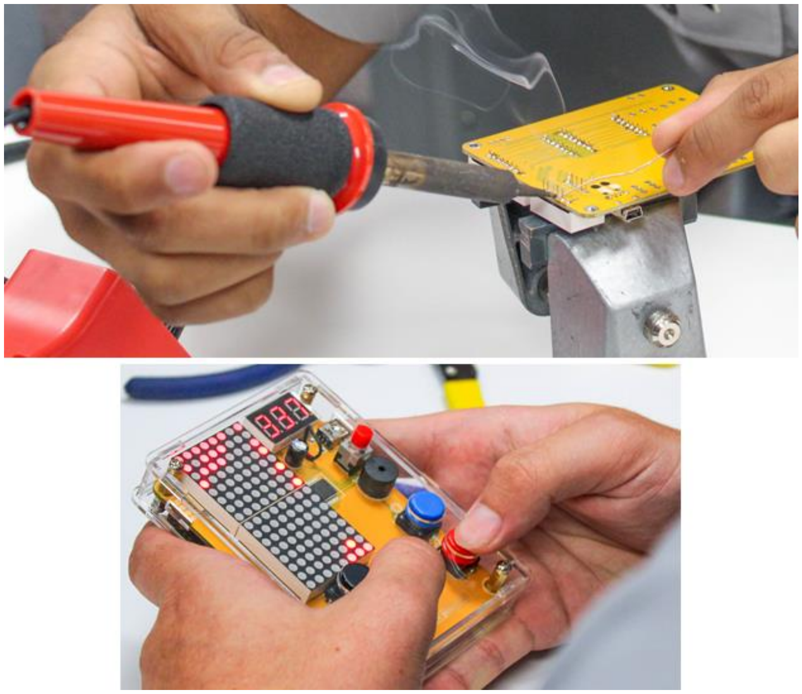

Figure 5. Soldering project: video-game circuit board.

Engineering Design Problem

- You are a small unit leader located on a mountain top in a Top Secret Area of Responsibility (AOR). Bad weather has made aerial resupply impossible and your unit desperately needs resupply. A logistics element was able to get the supplies to a plateau 500 meters below your location. You have limited items at your disposal.
- Apply engineering science and analysis to aid you in designing and building a "Highland Lift."
- For this project, the lift is scaled to 1 lb that must be lifted 2 feet, at which point your apparatus should stop automatically.

Figure 6. End-of-semester project: the objective is to lift a 1-lb weight to a height of 2 ft.

The instructors designed the project such that the students would achieve its objective by applying theory and practice learned (very recently) in their discipline-specific modules. The student-teams were required to lift a 1-lb weight to a height of 2 ft. All teams were provided with an Meccano Erector 19602 building kit, a Lego Simple & Powered Machines 9686 motor-and-gear set, and a SparkFun Inventor's Kit. The teams were allowed to choose the surface on which the weight would rest initially. They were allowed to affix their lift structure to a desk or tabletop anywhere in the lecture hall. The Meccano kits provided rigid structure, the Lego Machines set contained a motor and gears to accomplish the lift, and the SparkFun kit controlled the motor/gear apparatus. Programming the Arduino RedBoard in the SparkFun kit required at least one of the students on each team to bring a laptop and to install on it the Arduino-C development environment (which they had used in the computer lab during an earlier part of the *Intro* course).

The student-teams were given the guidance shown in Fig. 7. The weight would be lifted using a gearbox consisting of at least 2 interlocking pieces, which requires application of theory regarding gear-ratios and torque, knowledge of which the students acquired during the Mechanical Engineering module. The lifting mechanism would be controlled using a transistor and the height of the weight would be measured using an ultrasonic sensor, both of which the students learned about in the Electrical and Computer module. The gear-box and control/sensor unit would be held in place using a rigid static structure, which the students learned about in the Civil and Construction Engineering module. In Fig. 8 are pictures of (a) one of the students' free-standing tower structures, (b) a gear-box with a weight being attached to it before testing, and (c) a height-sensor and motor-control circuit.

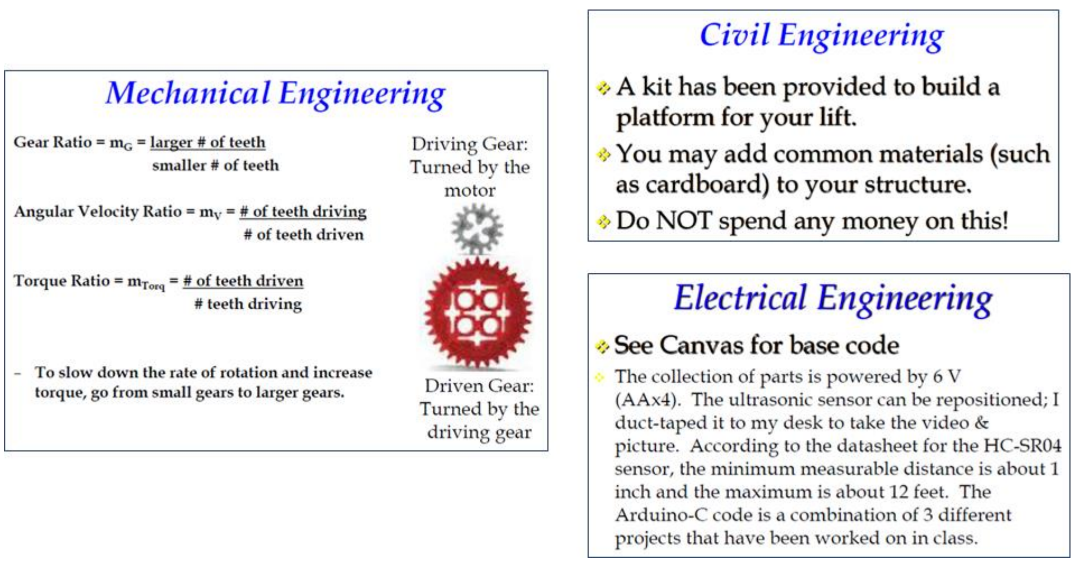

Figure 7. End-of-semester project: guidance provided to students; solution in 3 parts.

The students performed well on this project. Some students found a new appreciation for the strength (or weakness) of their building materials when their upright structure collapsed while attempting to lift the weight. Other students better appreciated the relationship between gear-ratio and torque when they observed that their choice of gears would not lift the weight at all. Still other students grew to appreciate how exacting electrical-prototyping can be when they realized that their motor would not turn if their power- or control-circuitry was wired improperly or their microcontroller was programmed improperly. To the delight of their instructors, all teams present at the final-exam session were able to achieve the objective of the project.

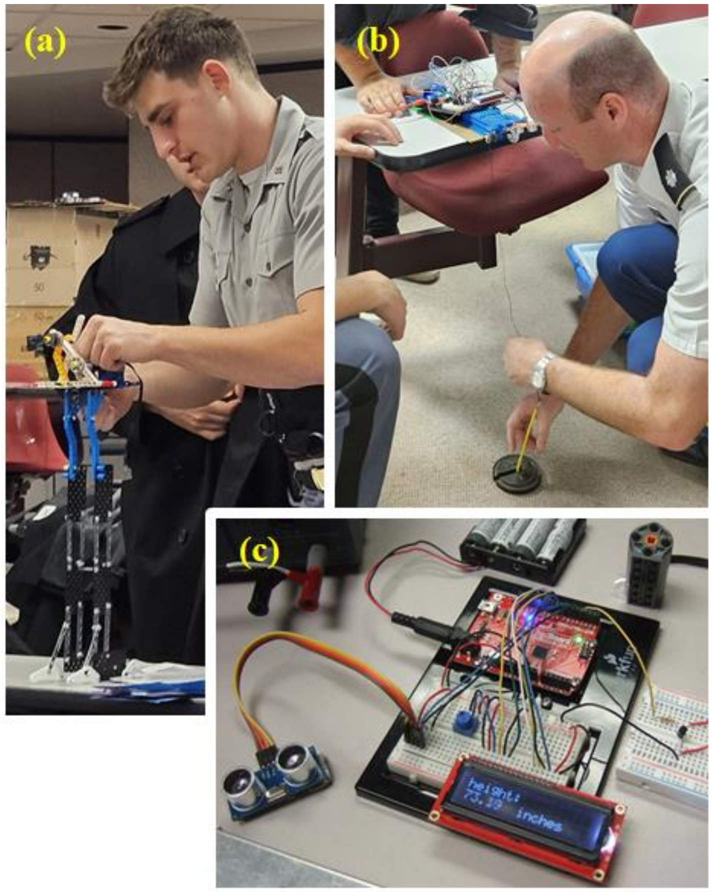

Figure 8. End-of-semester project: (a) rigid structure to hold the lift mechanism, (b) gear-box with a weight attached to it, and (c) height-sensor and gearbox-control circuit.

Students' Awareness of our Different Engineering Disciplines

To track their students' familiarity with different engineering disciplines and their confidence in engineering as a major, the authors administered a survey -- assigned as homework, available on the course website -- containing 8 questions:

1. How familiar do you believe that you are with the purpose of Civil Engineering and employment opportunities for Civil Engineers?
2. How familiar do you believe that you are with the purpose of Computer Engineering and employment opportunities for Computer Engineers?
3. How familiar do you believe that you are with the purpose of Construction Engineering and employment opportunities for Construction Engineers?
4. How familiar do you believe that you are with the purpose of Electrical Engineering and employment opportunities for Electrical Engineers?
5. How familiar do you believe that you are with the purpose of Mechanical Engineering and employment opportunities for Mechanical Engineers?

6. How confident are you that a *scientific, technical, engineering, or mathematical* (STEM) field is an appropriate field for you to study?
7. How confident are you that an *engineering* major is an appropriate major for you to study?
8. How confident are you that *your currently-declared* major is an appropriate major for you to study?

For the discipline-specific questions, the students were asked to express their familiarity on a scale of 1 to 5, with 1 representing "not familiar at all" and 5 representing "very familiar". For the confidence in STEM/engineering questions, the students were asked to express their confidence on a scale of 1 to 5, with 1 representing "not confident at all" and 5 representing "very confident".

The survey was completed by all of the students in the course at three different times: when approximately 1/3 of the course was completed (after their first discipline-specific module), when approximately 2/3 of the course was completed (after their second discipline-specific module), and at the end of the course (after they had been taught by all 3 professors addressing all 5 disciplines). The students' responses, in aggregate, are provided in Figs. 9 and 10.

Interpretation of Survey Data and Future Work

For *all* of the discipline-specific questions, the students indicated that their familiarity grew over the course of the semester. All 5 disciplines saw an almost full-point increase in the mean of the 5-point score. For all of the STEM/engineering questions, the students' attitudes remained largely unchanged: each of the questions saw a slight uptick at the 2/3 mark, but all 3 returned to their original mean by the end of the course. The authors interpret this data to mean that (a) their students were already pretty confident that engineering was the right choice-of-major for them when the entered the *Intro* course, (b) the freshmen did indeed learn more about each of their institution's engineering disciplines, and (c) most students will wait-and-see if their particular major is indeed the right one for them.

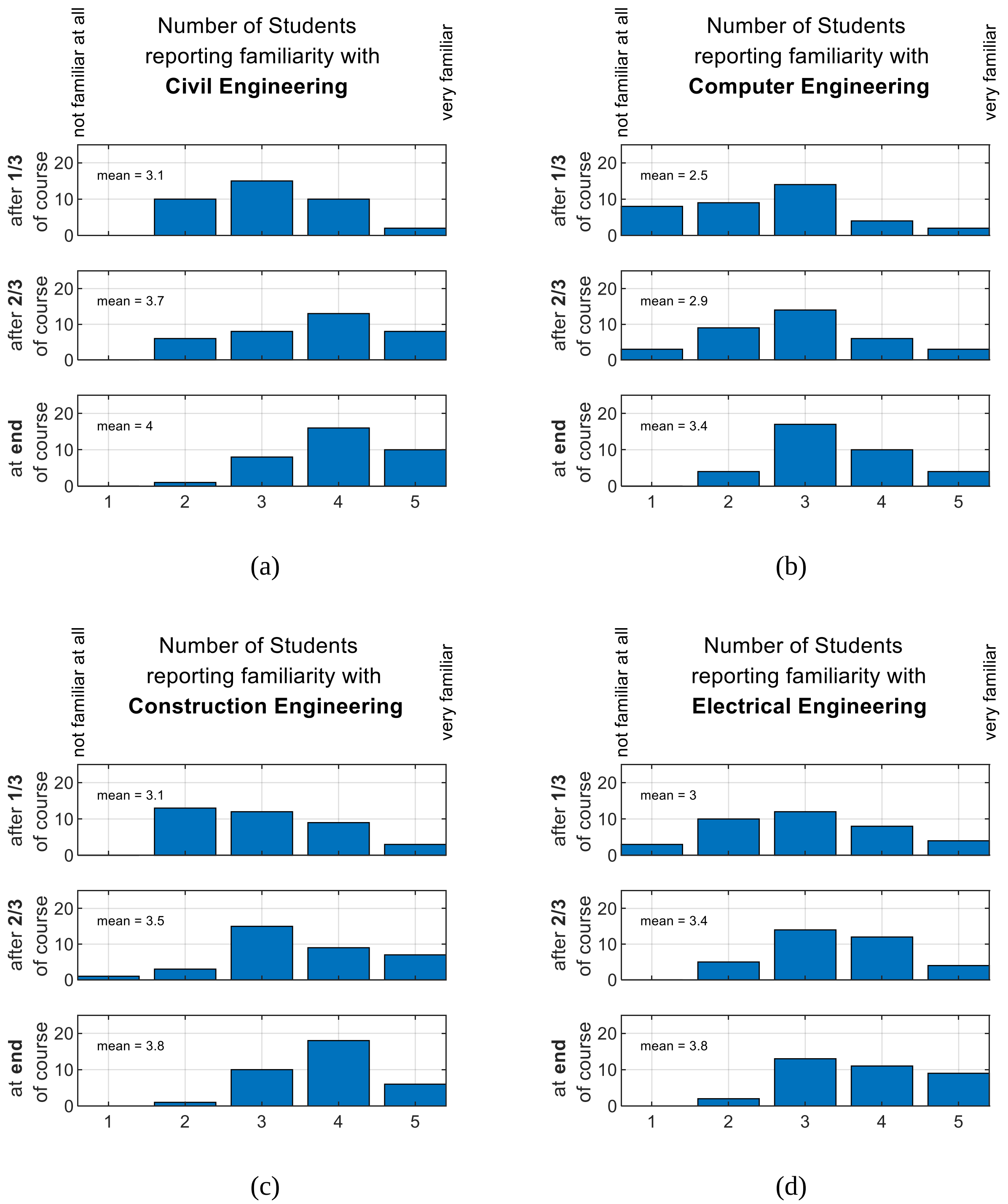

Figure 9. Student responses to these survey questions:
How familiar do you believe that you are with the purpose of…
(a) Civil Engineering and employment opportunities for Civil Engineers?
(b) Computer Engineering and employment opportunities for Computer Engineers?
(c) Construction Engineering and employment opportunities for Construction Engineers?
(d) Electrical Engineering and employment opportunities for Electrical Engineers?

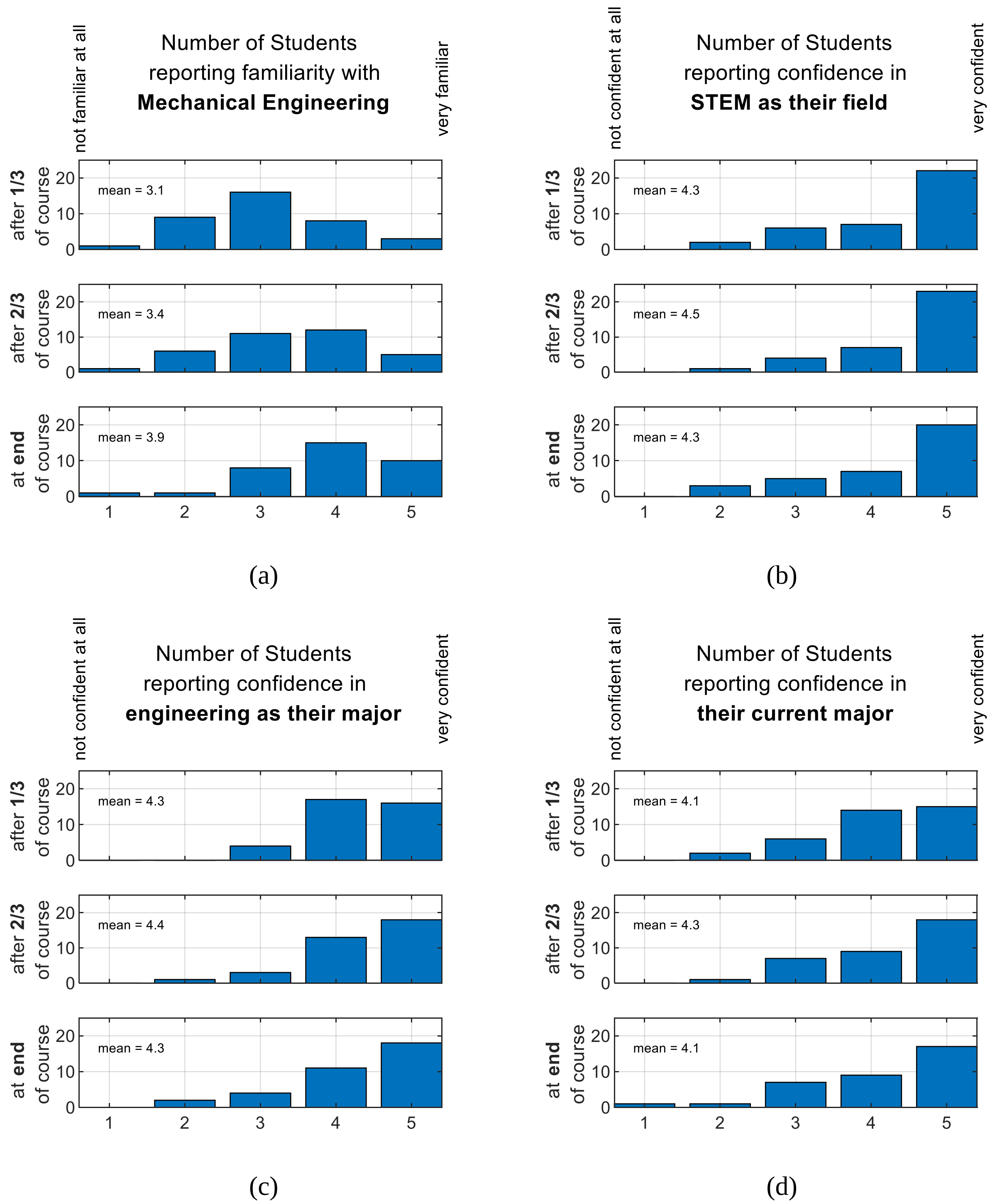

Figure 10. Student responses to these survey questions:

(a) How familiar do you believe that you are with the purpose of Mechanical Engineering and employment opportunities for Mechanical Engineers?

(b) How confident are you that a STEM field is an appropriate field for you to study?

(c) How confident are you that an engineering major is an appropriate major for you to study?

(d) How confident are you that your currently-declared major is appropriate for you to study?

In future semesters, when all freshmen (approximately 150 incoming engineering majors) are enrolled in this same *Introduction to Engineering* course, the authors intend to (a) track changes in individual students' scores on this survey across all 3 rounds, (b) compare data regarding retention of students against historical data collected from the discipline-specific *Intro* courses, and (c) track the migration of students between majors [26]. The authors consider their pilot of the discipline-agnostic *Intro* course to be largely a success. Below are some comments provided by students on their end-of-course Student Evaluation of Instruction forms:

> responding to *What did you like most about this course?* "Group projects."
>
> "The thing that I liked the most about this class was how hands-on it was."
>
> "This course was constructed to teach us about each type of engineering and it succeeded in teaching me because I did not understand what civil and mechanical engineering were until this course."
>
> "I enjoyed seeing all of the engineering disciplines from enthusiastic professors from their respective departments."
>
> "I loved the three-discipline approach to Engineering 101. I believe it accomplished its goal of giving the students a deeper understanding of what other disciplines do and allowed us to make an informed decision on what major to choose."

The 3rd and 5th comments reproduced above are particularly encouraging, as one of the core objectives of the authors' piloted *Intro* course was for their students to learn about engineering disciplines aside from their declared major. The consistent and significant increase in "familiarity" indicated by the authors' periodic surveys indicates that their students' awareness of different engineering disciplines did indeed grow over the course of their *Introduction-to-Engineering* class.

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