

An Analysis of First Year Students' Changing Perceptions of Engineering Design and Practice

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Introduction

A vast body of literature is available to guide freshman engineering introductory courses. This paper builds on three key pillars within the literature that focus on 1) project-oriented learning, 2) team-based learning, and 3) freshman design experiences. Design experiences at the freshman and sophomore level can help increase retention rates for engineering students and help students better appreciate what engineers actually do. These courses and experiences can also form a cornerstone for the students' learning and motivate students to learn engineering analysis techniques.

Because of widespread inaccuracies about what engineers do,¹ one of the learning goals of many first-year engineering courses is to clarify the perception of the engineering profession in the eyes of students. In theory, students can then identify themselves as engineers and thus make confident, informed decisions regarding their career path in one of the engineering disciplines. This increased confidence leads to better academic performance and increased retention of students in engineering curriculums.²

Many methods are used in freshman engineering courses to introduce students to the engineering profession, such as project-oriented learning, team-based learning and design-based learning. There is a vast array of data available illustrating the effectiveness of these methods individually. The objective of this study was to determine the combinatory impact of these methods in establishing a solid understanding of the engineering profession in freshman engineering students.

Literature Review

Freshman introduction to engineering courses typically aim to address one or more of the following issues: 1) helping students develop their concept of what engineering is and what engineers actually do, 2) building a foundation for the students' success in the engineering curriculum, and 3) increasing retention of engineering students. Retention of engineering students is a complex issue that has been studied extensively.³ Retention and graduation have been linked to student attitudes toward math, science, and computers⁴ as well high school GPA and math SAT scores.⁵ A hands-on first year engineering projects course has been shown to improve retention of engineering students.⁶ Stevens et. al recommend that progress through the engineering curriculum should be viewed as individual pathways rather than a homogeneous pipeline and that a student's identification with engineering is their compass along the pathway.⁷ This line of thinking suggests that retention might be improved by efforts to help freshmen develop a strong identification with engineering.

Helping students develop a better understanding of what engineers do has been linked to increased confidence in the choice of an engineering major.⁸ In order to help freshmen learn what engineers actually do, it is essential to expose them to design. Some have asserted that designing is at the core of what it means to be an engineer and that "the purpose of engineering education is to graduate engineers who can design."⁹ But it is widely agreed that teaching design is challenging.^{9,10} Evans goes so far as to say that design itself is hard to define: "Even 'design'

faculty—those often segregated from 'analysis' faculty by the courses they teach—have trouble articulating this elusive creature called *design*."¹¹

One of the key concepts that the authors attempted to teach freshmen engineering students is that design needs to involve both divergent and convergent thinking.^{9,10} Divergent thinking takes place in the concept domain and seeks to generate as many alternatives as possible. Divergent thinking is often considered to be at odds with a deterministic, engineering science approach.⁹ One interesting result of this paper is that the word brainstorming (referring to divergent thinking) was used much more often in the students' definition of design by the end of the course. In contrast, convergent thinking refers to a process of questioning and thinking that seeks to reveal facts and narrow down options to arrive at the correct answer. Convergent thinking is closely aligned with analysis based on engineering science.

Course Pedagogy

The overarching vision for this course was to provide students with an accurate view of what engineers do. Supporting this vision, course goals included introducing the engineering design process, practicing this process on three design projects in different engineering disciplines, and providing foundational tools for strong technical communication skills. The student learning objectives that connect the course materials to these goals are included in the appendix of this paper.

Instruction on the engineering design process was included during the second class period (75 minutes) of the semester and detailed divergent-convergent thinking¹⁰ and included nuances from other best practice articles.^{12,13} Based on their declared engineering majors, students were then divided into multidisciplinary teams for the semester, supporting ABET Criterion 3, outcome d.¹⁴ The teams in each section completed projects in each of three engineering disciplines: civil, electrical and mechanical; albeit in different orders depending on the section. The projects were rotated through each section so that all student teams were assigned each project. The projects included the design, construction, and testing of:

- A wind turbine where students predicted the current produced;
- A projectile motion machine for launching a tennis ball 15 feet;
- A two-foot span wooden truss bridge that holds 50 pounds.

Each design project had a five week duration culminating in a demonstration, a design report, and a presentation from each team. This emphasis on technical communication was guided by two class periods focused on verbal technical communications and two on written technical communication. It was intended that these class periods, combined with three significant opportunities for detailed feedback, provided the tools to foster the desire for continuous improvement in technical communication skills (towards ABET Criterion 3, outcome g.)

Three faculty members co-taught three sections of this course, rotating sections every five weeks (concurrently with changes in projects.) The course was categorized by Southern Illinois University Edwardsville as a new freshmen seminar, limiting enrollment in each section to a maximum of 25 students. Because Adams et al. concluded that a multiple-perspectives method could help to engage the engineering students of the future,¹⁵ co-teaching was viewed as a way to introduce students to faculty and material in diverse areas of engineering. Additionally, the

course included an entire class session where practicing engineers were invited to speak to and answer questions from the class in a panel session format, as supported by Rippon et al. 2012.⁸

The University requirements for this type of introductory class dictated that the curriculum include University values, critical thinking, and ethics. One class period and two homework assignments were dedicated to University values. The first homework assignment focused on the value of citizenship, with the goal of engaging students in the School's engineering community. This assignment required students to attend a chapter meeting of an engineering student organization, then complete an online discussion board post about their experience. As Meyers et al. note, freshman are more apt to listen to the advice of other upperclassmen than faculty members¹⁶ and such engagement could lead to a forum for soliciting this advice. The second homework assignment was focused towards the University value of openness. This assignment required students to read or find an article about a non-technical dilemma that engineers face, and complete a discussion board post and response about the article. Faculty provided articles on topics such as working with people you don't like, disconnects between engineers and city planners, rural versus urban student resources, and minorities in engineering. The key message behind this assignment was that you need to be open and receptive in order to understand a different point of view and work together effectively.

The content and requirements for the three design projects were adequate to meet the critical thinking requirements. Faculty dedicated one class session to engineering ethics, reviewing the National Society of Professional Engineers Fundamental Cannons¹⁷ and leading a class discussion of a real-world ethical dilemma (towards ABET student outcome f)

Methodology

The methods included student survey data, test performance, and a text analysis of before and after student writing. The student surveys were collected during the first day of class and focused on measuring student's definitions of 1) what an engineer does and 2) what is the engineering design process. The researchers typed the student responses and used Atlas software to compile the responses and identify commonly-used words for each of the two question responses. Data from approximately 75 students was included in this study.

Throughout the semester, the researchers met at least every two weeks to share and record observations from the different sections and to discuss pedagogy, ensuring consistent instruction. These observations are integrated into the findings in the following section.

Test performance data was measured on the final exam, based on student descriptions of these same two definitions. Again, Atlas software was used to compile the response and identify the commonly-used words. Next, the researchers compared the trends in the use of common words for each definition, respectively.

Analysis and Findings

When asked, "What does an engineer do?" the findings suggest that the most significant changes were increases in words such as product (+350%), problem (+315%), efficient (+300%), process (+250%), solution (+200%), and solve (+192%) as shown in Figure 1. There were also

increases in terms that include use (+136%), idea (+133%), people (+133%), and math (+100%.) Only modest increases were found in the terms life, make, new, improve, world, and design.

On the contrary, students used certain words less after completing the course, indicating that they understood that engineers are more active in the planning and specification of a solution rather than the actual construction activities. Specifically, students decreased their use of build (-74%), structure (-67%), construct (-25%), and create (-13%). Note that construction management students, whose career may include a large portion monitoring "building" do not take this course and were not in the sample.



Figure 1: Differences in Before and After Responses to "What does an engineer do?"

Interestingly, students also reduced their use of terms including work, help, and society. Further investigation suggests that students might have replaced these words with more-accurate terms. For example, as use of the term work decreased (-38%), the term make increased (+29%). Additionally, as the term help decreased (-55%), the terms life (+33%) and improve (+17) both increased. Last, when students decreased their use of the word society (-67%), they also increased their use of the words people (+133%) and world (+13%.) Figure 1 details these findings. Note that if terms were not used both before and after, they were not included and will be discussed later.

To demonstrate this transformation, two examples are included. In all of these questions, students were asked, "What does an engineer do?"

Student x Before: "Solves practical problems to the real world."

Student x After: "An engineer uses practical knowledge to solve problems while maintaining a code of ethics."

Student y Before: "Design and experiment with solutions to everyday problems."

Student y After: "An engineering solves real world problems that provide a benefit for society."

Next, the authors evaluated how word choices changed when students were asked, "What is engineering design." Again, these questions were asked on the first day of class and on the final exam. As Figure 2 illustrates, the largest change was an increase in the word brainstorm; a surprising increase of 2550% (2 students before and 53 after.) Brainstorming is closely related to divergent thinking, so this increase indicates an important shift in the students' understanding of design. The other words that increased in use are similar to those in Figure 1, but different in their amount of increase.



Figure 2: Differences in Before and After Responses to "What is engineering design?"

Students answering "What is engineering design?" more frequently used completely different terms before and after. Thus for a clearer picture, the authors created Figure 3 to highlight the frequency that some terms that were used after, despite not being used before the class. For example, test was used 55 times in student responses after the class, compared to zero before. Similarly, the terms divergent (16 uses) and convergent (14 uses) entered students' vocabulary during the class, at similar levels of use. Note that these words were used by approximately 20 percent of the students. These and other findings are shown in Figure 3.



Figure 3: Increases in Student Word Use in Response to "What is engineering design?"

Conclusions

As expected, students' definitions improved in accuracy, but the most important findings related to which misconceptions were being corrected. The study found that as students refined their definition of an engineer, they increased their use of terms such as product (+350%), problem (+315%), and efficient (300%); while reducing their use of build (-74%) and structure (-67%). The text analysis also revealed that student definitions of the engineering design process increased their use of the term brainstorming by an astonishing 2500%. Brainstorming is related to divergent thinking, so this increase shows an important development in the students' understanding of the design process.

Combining several best practices on freshman engineering pedagogy has yielded large changes in student perceptions of what engineers do and what design means. Future work should evaluate the longitudinal effects of this course on student persistence in engineering. At the time of this writing, retention information was not available.

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Appendix: Selected Course Learning Outcomes

- Statics
 - Apply correct units to statics solutions
 - Differentiate between scalars and vectors
 - Convert between scalar and vector forces
 - o Differentiate between collinear, concurrent, and coplanar force systems
 - o Add systems of forces into one resultant force vector
 - o Resolve one force vector into components
 - o Apply free body diagrams to trusses
 - o Apply method of joints to determine the forces within members of a truss
 - Recommend material type and size to resist expected forces
 - Design a wooden truss based on the details provided in class.
- Dynamics
 - Perform projectile on a ball in free flight
 - Determine potential energy due to gravity and preloaded springs
 - Determine the kinetic energy of a moving mass or rotating pendulum
 - Use conservation of energy to determine the launch velocity of a ball released from a catapult or other device
- Circuits
 - o Become aware of the different paths within Electrical and Computer Engineering
 - o Understand how Wind Turbines operate.
 - Understand the process of how permanent magnets induce a voltage in a coil of wire.
 - Be able to calculate the amount of power that can be generated by a Wind Turbine.
 - o Understand the electrical quantities: Power, Voltage, Current and Resistance.
 - o Understand the difference between Alternating Current and Direct Current.
 - Be able to perform simple DC circuit analysis.
- Technical Writing
 - o Differentiate between relevant and irrelevant information when writing a report
 - Demonstrate professional writing style
 - o Organize effective presentations and reports
 - Create clear, appropriate, and effective figures/tables
 - Use thesis statements when constructing paragraphs
 - o Identify proofreading techniques that work best for you and your group
 - Design effective presentation slides
 - Organize a clear presentation
 - Select tools to help mitigate nervousness during presentations
 - Clearly describe a technical process
 - o Identify common mistakes in technical communications
 - Recognize how to personally improve your technical verbal communication
- Ethics and University Values
 - Describe opportunities for becoming engaged in student activities on campus and in the School of Engineering
 - o Discuss how the value of openness is valuable to your future career and life success
 - Demonstrate excellence in applying the engineering design process to three group projects
 - Demonstrate integrity by creating reports that are your team's work alone and that correctly cite sources
 - o Develop wisdom by sharing knowledge within a project team