Work in progress: First-Year Students' Definitions of Engineering Practice

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Introduction

This work-in-progress paper investigates how engineering students define the practice of engineering after completing their first year (completed the first two semesters) of an engineering degree program. Engineering is a complex degree program because many students have to start preparing for this degree while in high school by building up their mathematics and science knowledge. For engineering students to start an engineering degree program, they start with calculus, and are considered behind schedule starting with a lower level mathematics course. Although high school students may start planning for an engineering degree program during their freshman to senior years, many students do not know what the different disciplines of engineering are and what they do. In Changing the Conversation [1], they show that many high school students do not have a realistic comprehension of the practice of engineering. This research examines how students define the practice of engineering after their first year at the university. This work contributes to the growing body of knowledge of how students consider engineering practice after being in a freshman level introduction to engineering course. This paper is a sample of the data collected and analyzed after the students were exposed to one 2 credit hour course in an introduction to engineering course. The authors' hypothesis is that students will change their definitions of engineering when they are exposed to a variety engineering activities. Since this is a work-in-progress paper, the data has not yet been collected for the exposure to the second semester lab course.

This work will help faculty, advisors, and administrators in first year programs understand what their students are learning in the first year, how students are defining the practice of engineering, and the current themes that the authors found from students definitions of the practice of engineering. The researchers thought it would be helpful to include an analysis of the syllabus used in the class and how much time was dedicated to each topic to see if there was any correlation to how the students were defining the practice of engineering.

Background

The career of engineering has long carried the reputation as a field of people that are good at math and science [2]. However, now it is recognized as a distinct and separate discipline with its own components of thinking and execution [3]. This research investigates what students' definition of the practice of engineering is following the completion of their first year in engineering school.

Science and design have long held a feud with one another, starting in the 1920s and continuing to the 1970s, when the 'modern movement of design' transitioned from science inspired design methodologies to claims of disarray in science that should encourage 'designerly' ways of knowing, thinking and acting [4].

More recently, the troubled past of science and design have started to converge with recognition that design is different, but has much to contribute to a renewed epistemology of science [5]. As design methodology continues to develop, engineering is following in this pursuit of design with works in engineering design methods by Tjalve [6], Hubka[7], Pahl and Beitz [8], French [9], Cross [10], and Pugh [11].

Along with science and design, additional modes of knowing, thinking and acting are emerging as requirements of not only an engineering student but a professional engineer in practice. Critical thinking, as described by Paul and Elder's [12] framework, encompasses reasoning from intellectual standards to develop intellectual traits. With these additional layers of expectation for an engineer we began this study by utilizing Figueiredo's [13] four dimensions of engineering knowledge comprised of: social sciences (engineer as sociologist), basic sciences (engineer as scientist), design (engineer as designer) and practical realization (engineer as doer) to evaluate the knowing and thinking of freshman engineering students. Our work has lead us to a different set of dimensions, based on the review of student responses, that we believe is more fitting to the flow of knowing and thinking within the practice of engineering. This method of coding student responses can then help faculty in the evaluation of meeting course objectives and providing adequate timeframes for objectives to meet the needs of all students.

Purpose

The study has been designed to examine how first year engineering students interpret the practice of engineering and how they view it in relation to either themselves, others, and the world. The research question that we address in this paper is: How do first year engineering students define the practice of engineering after completing their first year of coursework?

Through this work, engineering educators will have a basis for which to quantify their student's development and overall understanding through the execution or re-design of engineering curriculum.

Design/Method

Students enrolled in the three-semester engineering program, at the end of their First-Year of coursework and the beginning of their required summer mathematics course, students were asked to describe the practice of engineering in an open-ended questionnaire. The directions read: In 150-200 words, describe what the practice of engineering means to you. We surveyed 362 students, and received 349 responses. The researchers analyzed a random sample of 50 responses for this work-in-progress paper. These responses were coded using thematic analysis using open and axial coding [14], resulting in six dimensions. Considering the quality of the qualitative data [14-15], the theoretical validation of this data, while limited by including participants only from a large, public, research institution, other modes of variation are present. Procedural validation was established through the consistency of message, delivered through an online Blackboard assignment to all the students at the same time. Students received 5 points, same as one homework grade, for completing the online questionnaire. The estimate for this assignment compared to students' overall grade in the course was 0.05%.

Further, the constant comparative method was used to make sure researchers were staying consistent with coding the definitions of the practice of engineering [15]. The researchers met after coding ten responses, talked at length about the themes they each found, re-coded the first ten responses and coded ten new responses, then met again to make sure the coding was consistent. A limitation is that communicative validation was impossible in this study design, because this data was collected using an open-ended questionnaire, so there was only one-way communication. This approach had the benefit of enhancing process reliability through the use of a consistent survey message given to all the students [15].

Results

Through the analysis, researchers found student understanding of engineering practice was conceptualized through components beyond Figueriedo's [13] four dimensions. The dimensions we found in students' responses were within the broad concept of engineering processes. With Figueriedo's [13] dimensions guiding our analysis, we established six dimensions that fully encompassed the themes of students' responses. The six dimensions included (key concepts provided in parentheses): teamwork (connecting to people, collaboration), theoretical (science, math concepts), creativity (innovation, creating, inventing), design (design, blueprints, efficiency), problem solving (critical thinking, reasoning), and outward perspective (making the world better).

Themes

An overview of the process of constructing each theme and student exemplars are provided below.

The dimension of ***Teamwork*** included responses describing engineering practice with teamwork and collaboration either within the description or as the description of the practice of engineering. There were 17% of student responses that included a teamwork/connection to people with engineering.

Responses that demonstrate teamwork, include: "…*What I really appreciate about practicing engineering is the fact that teamwork is really emphasized. The best creations come from several engineers working together and bouncing ideas off of one another on certain projects…*" (F1016) and "…*Team work in engineering can make a huge difference in the amount of work accomplished. Practice of engineering is a major responsibility and not only requires a large amount of work and focus, but also morals and communication skills …*" (F1516)

The ***Theoretical*** dimension described ideas of engineering practice based mainly on science and math concepts through logical modes of thinking. There were 33% of student responses that included some theoretical aspect of engineering in their definition.

Reponses that demonstrate theoretical include: "…*The practice of engineering means to explore the limits of science, to make possible what once was thought to be impossible, to improve, and build upon what other, out of the box thinkers thought of years ago….*" (F0916) and "…*The discipline is the application of science for the practical use of a society...*" (F2216)

Creativity was a dimension that emerged due to student's use of verbs like: innovation, creating and inventing within their response. There were 43% of student responses that included creativity as their definition of engineering.

Responses that show creativity as a theme are as follows: "*To me, engineering is the never ending task of improvement. It is a competition constantly. The contestant pursuit of knowledge and not only improving operations but also figuring out new ways to accomplish a task that is faster, cheaper, and with improved quality*." (F4316) and "…*The practice of engineering means being responsible and accountable to things on a higher level, as well as innovating and designing new things in ways that have not been done before*." (F3016)

Design became a dimension designated with language such as design, blueprints and efficiency within the response given by the student. A *design* response could also contain ideas leading to improvement of design in some manner. There were 60% of student responses that included themes of design for the practice of engineering.

Responses that include *Design* as a theme are as follows: "*The practice of engineering means planning out blueprints that take into consideration every possible thing that can occur if the object of the blueprint were to be real and make that object do jobs that make life easier.*" (F1116) and "…*Engineering is a wonderful practice because it involves designing and improving the world in which we live in*…" (F2316)

The ***Problem Solving*** dimension emerged based on student responses that included descriptors of critical thinking and problem solving. Responses that used descriptors of "real-life" or "everyday" problems, "critical thinking" or "problem solving" were grouped within this dimension. This dimension was created because of the various responses that described the practice of engineering as a persistence toward a solution or use of resources to accomplish the task at hand. There were 69% of student responses that include critical thinking and problem solving aspects to the response. Without this dimension a large portion of the responses would not have adequate representation within the coding instrument.

Responses that include the *Problem Solving* dimension are as follows: "*To me the practice of engineering is learning how to find solutions to everyday problems and improve on the technology we have today*" (F2416) and "*Engineering to me means practical problem solving and logical thinking through tough situations. It means that even if you do not know the answer or how to reach it you will have some way to find the answer*." (F2516)

Table 1: Percentage of student responses for first 5 dimensions with sample student responses

Dimension	Percentage of student responses containing dimension	Sample Student Responses
Teamwork	17%	*"…It is also vital for engineers to communicate with each other to get multiple views on an idea, and with their combined experience and knowledge it is easier to find a solution." (F3716)*
Theoretical	33%	*"...A common and central skill that must be achieved by all who wish to succeed in engineering, is the ability to generalize knowledge, determine and describe the problem that needs to be solved and the ability to make novel connections between previously unconnected skill sets. This is why it is imperative for every engineer to have at the very least a basic working knowledge of chemistry, physics, and computer science. Mathematics is the most important skill set for the engineer, for it is the common language in which most of his or her problems are described and solved." (F0516)*
Creativity	43%	*"...In my perspective, I see engineers as the main inventors of every solution that is needed around the world." (F4816)*
Design	60%	*"...engineering means making certain processes more efficient and researching to make products better for consumers." (F1716)*
Problem Solving	69%	*"Engineering to me means critical thinking; finding solution to real world problems and I believe is also means estimating and educated guessing." (F1816)*

The ***Outward Perspective*** dimension became apparent after an overall binary effect was identified within the student responses toward making the world a better place, either directly for their community, the broader world, people in third world countries, or the environment. This dimension became increasingly important as analysis of responses continued because it accounted for the conceptualization of student views and thinking toward the practice of engineering. 60% of the student responses coded had an outward perspective. This perspective was consistent throughout the responses as having altruistic characteristics of the student conveying selfless descriptions of the practice of engineering as working toward a better society.

Responses that contain *Outward Perspective* include: "*The practice of engineering means designing, creating, building, re-building, etc. in unique and innovative ways in order to make the world a more developed place…*" (F1016) and "*Using the skills and practices of science technology mathematics and analytical thinking to build things and improve the world around us for the betterment of society. It means to be held to the highest accountability...*" (F3016)

The following responses do not have an outward perspective view: "*The practice of engineering to me is applying the engineering method to problems to come up with solutions that can be refined…*" (F0716) and *"Engineering to me seems like the practice of streamlining efficiency and solving the problems associated with newly developed methods of building things."* (F0616)

Table 2: Outward Perspective summary table of student response examples and non-examples

Percentage of student responses	Student response examples containing Outward Perspective	Student responses not containing Outward Perspective
60%	*"Engineering is a discipline in which I can take my understanding of the natural world and apply it to the creation of a better civilization. Most importantly, the engineer has a duty to the safety of the people and societies that use his or her creation." (F2216)*	*"The practice of Engineering means to design, build, and maintain structures or machines, etc. using top of the line technology, teamwork, and knowledge. Some engineering will only focus on designing, some will only focus on building, or some will only focus maintaining/operating." (F1416)*

Cross Coding between *Outward Perspective* to the other 5 Dimensions

The *Outward Perspective* dimension within student responses emerged unexpectedly as researchers noticed student's feelings toward engineering practice either containing an overall essence of connection to people and society by making the world better or not. While it could be expected that an engineering student with a worldly view of the practice of engineering would also express views in creativity, design and critical thinking we found the strongest connection to an outward perspective to be with the creativity dimension. Through a holistic evaluation, the researchers were able to determine student responses with a view of innovation, creating and inventing also felt engineering practice is meant to better the world in a variety of ways.

Interestingly, the design, problem solving and teamwork dimensions had the lowest amount of overlap with outward perspective dimension. This discovery provides an unexpected insight that students do not always draw connections between learning objective outcomes as expected or planned. Engineering design is typically conducted in a collaborative, team atmosphere; a description that is true of the experience of the students that responded to the question analyzed for this study. More effective teams are generally comprised of more altruistic team members; as opposed to less effective teams made up of single-minded self-motivated individuals[16]. The researchers, sharing a goal toward educating First-Year engineering students in effective teamwork strategies, hoped to see a clear and evident overlap of responses within the dimensions of design, problem solving, teamwork, and outward perspective.

However, these hopes were not met within this analysis and provisions investigating this lack of connection represented in the student responses provides opportunity for more explicit and direct teamwork experiences for future First-Year coursework design and implementation.

Table 3: Cross-Coding percentage results of Outward Perspective overlap with the 5 dimensions

Outward Perspective	
Creativity	67%
Theoretical	64%
Teamwork	57%
Problem Solving	55%
Design	52%

Analysis of course syllabus and course timeline schedule

Students that responded to this survey had just completed an introductory course for their engineering coursework that included learning outcomes of: applying critical thinking framework to engineering design problems, explaining steps to an engineering design, summarizing effective strategies for dealing with interpersonal and communication problems that arise in teamwork, and identifying ethical and professional issues of engineering practice. Through an analysis of the course schedule and lesson timeline we found a significant amount class time was devoted to discussion focused on the topics of the course learning outcomes, such as: critical thinking and decision-making (19% of class time), design (35%), teamwork and communication (15%), and ethics and professionalism (15%). Alongside discussion, class time was allotted for interactive group work on design projects that applied a combination of the course learning objectives listed above. Within this context, the student responses analyzed for this study reiterated the course learning outcomes by including themes within *Problem Solving* (69% of student responses), and *Design* (59.5). The course objective of the First-Year introductory course was to emphasize thinking toward problem solving and engineering design process; the results from coding the student's responses reinforce instructional procedures that may have crafted student thinking and expression. The researchers found no proclivities within the student responses toward identifying professionalism or ethics; a result that has provided another area for improvement for the First-Year coursework design and implementation.

<u>Conclusion</u>

The most popular definitions for the practice of engineering were Problem Solving, Design, and having an Outward Perspective. Engineering is known for its problem solving, critical thinking, and designing. Engineering is not as well known for thinking of others and connecting the work to how it will impact people.

Creativity, Theoretical, and Connections to People, were less than 50% of the definitions. Teamwork (within Connecting to People) was the lowest at 17%. There is still a misconception that engineering is a one-person job, and that it is not a team occupation.

There is more work to be done on this topic. Specifically, research on how First Year programs can influence students' perceptions of teamwork and creativity as part of the engineering profession.

Future Work: This work is part of an ongoing study to assess the effectiveness of adding a lab course to the engineering curriculum to see how it affects students' perspectives of the practice of engineering.

Acknowledgements

Drs. Angela Thompson and Pat Ralston for their contribution for helping collect the data and their support for this work.

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