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WIP: What Does It Look Like: How Early College Engineering Students Describe What Engineers Do

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Introduction

This is a Work-in-Progress study that was initiated to explore the impressions that early college students have about what engineers do through the examination of student-generated short narratives. We also wanted to learn more about how engineering curricula have influenced their impressions, such as why many of them seem to have an abstract understanding of what engineers actually do when they describe engineering work as "problem solving." To complicate matters further, it has been argued that problem solving in an engineering course is a lot different from problem solving in the engineering workplace [1]. Therefore, students should have additional opportunities to expand their understanding of what engineers actually do.

It would be appropriate to state that most early college engineering students obtain many of their impressions of engineering from outreach programs and STEM-based courses on the secondary and higher education levels. Some students may develop a broader view of engineering through technical internships or cooperative experiences, but these opportunities are generally available only after the first or second year of college, when they have already committed to the engineering path of study. Therefore, we challenge the faculty of introductory engineering courses to consider how one or more brief reflective activities could expand their students' understanding of engineering through action rather than abstraction.

Before we can recommend modifications to the teaching of engineering at the early college level, we need to find out how students currently describe what engineers do and what might have contributed to their impressions. In our experience, simply asking them has resulted in a simplistic or abstract response. In order to elicit more thoughtful responses, we have designed a study to begin to answer the following research questions:

1) *How well do our first-year engineering students describe what engineers do?*
2) *How well can students communicate an understanding of what engineers do, when asked to write a brief story vs. answer a brief question?*

Background and Conceptual Frameworks

Many research studies have explored how students form an engineering identity and sense of belonging through a number of factors [2]. However, we found in the literature that the longstanding reputation that engineers are problem solvers may interfere with constructive problem definition and a lack of awareness of a problem's impact of possible solutions on society, including, for example, economic, social, cultural, and environmental factors [3], [4], [5], [6]. This has been asserted both in the United States and elsewhere as the way that engineering students consider their engineering identity [3], [4], [6].

While the ability to solve problems is important, the short- and longer-term effects of engineered solutions on a society and its environment may be disregarded or simply ignored [3]. This is ironic, given that at least one widely-accepted engineering code of ethics emphasizes its focus on public welfare [7]. It is also recognized that the fulfillment of beneficial public welfare goes beyond the mechanics of problem solving because modern engineering problems are ill-defined, multifaceted and include factors beyond the scope of technology [3], [4], [6]. The optimal solution for the public welfare may also lie beyond the requirements of a particular client or highly influential governmental or economic body and/or at the expense of other stakeholders [3].

A number of methods exist to characterize engineering identity, often through surveys or interviews [2], [3], [4], [6], [8]. These methods commonly ask questions about identity along the lines of "What is an engineer?" Prompts may elicit responses measuring depth, breadth, and similarities to other STEM-based identities in physics or mathematics [2], [8]. One such 2016 study administered a survey with multiple choice questions intended to identify and characterize four contributors to identity as constructs: performance, competence, interest, and recognition [2], [8], [9], [10], [11]. Hazari, et.al. emphasized that a STEM-based identity is not exclusive, but is influenced, in part, by a student's personal and social identities [11]. Further examination of these influences revealed that the first three constructs contributed to personal identity, whereas the last construct relates more closely to social identity [11].

A set of methods for qualitative analysis of responses to this question that we adapted to our study had coded the responses according to one of three perspectives: historical reference, i.e., mediator of STEM skills, designer/tinkerer, or "21st century" containing humanistic considerations, followed by assignment to one or more domains consisting of "individual, "social", and "systemic" [6]. Another international study was concerned with the identification of technical and professional skills that engineers should possess and explored the role of motivation in developing an engineering identity [4]. A later and more novel method for engineering identity was used to prompt students to "draw an engineer", in which the data were analyzed using methods for the visual arts [12], [13].

Our focus for this study was on themes of experience contributing to identity. A theme could also capture an ethos, such as service to the world and the reasons why engineers do what they do. Examples of themes can be found in the literature [6], [13]. While the literature does include codes related to activity, we were unable to find a specific focus on the <u>actions</u> that engineers take. This becomes important because an understanding of what engineers actually do in their jobs can help our students to imagine themselves as engineers more realistically. There is also the possibility that, when prompts are focused on action, responses may be abstract and relatively vague, using such phrases as "solve problems," or "design solutions."

While the engineering profession relies on the application of abstract concepts in math and physics, an engineer's work often results in a product with a concrete physical or virtual manifestation. The construct of "concreteness" is a measure of how a word refers to something perceptible, tangible, or specific, first made popular in Paivio's dual-coding theory, which says that concrete words activate perceptual memory as well as verbal, making them easier to remember than abstract words [14], [15], [16]. Later, context availability theory said that concrete words can be processed more easily because of the memory contexts [17]. Concreteness has long been shown to be very important in memory recall, and association. We propose that encouraging the development of concrete examples of engineering tasks will help students to connect with a more concrete concept of engineering identity.

Experimental Methods

This is a Work-in-Progress study in which the participants responded to two questions at two different times about what engineers do in order to reveal their perceptions of what engineering is and how they belong to the profession. Responses were analyzed for richness of description along with coding against awareness of both technical and humanistic domains.

Study Context and Participants

Our institution is a large, R-1 state university in the eastern United States. The study sample consisted of 87% male and 13% female engineering transfer students who were pursuing a one-semester version of an introductory engineering sequence. The population consisted of 86% male and 14% female engineering transfer students. These transfer students had declared an engineering or computer science major upon their application to the university.

The course contained a semester-long design project, along with technical and professional skill development. The design project was completed by design teams of six students each, which involved instruction and practice in team dynamics and teamwork. While the current professional development units do not currently explicitly address engineering identity, many transfer students were already committed to the engineering or computer science profession through their major-specific courses, which means that they already had a perception of what engineers do. Our overall goal was to explore and characterize these perceptions in view of the students' existing experiences and the reality of modern engineering work. This Work in Progress represents the earliest stages of our study.

Data Collection

Qualitative data were collected as a convenience sample from the responses to two prompts about what engineers do, administered at different times during the 15-week semester. The Week 1 prompt was as follows:

> *How would you describe what an engineer does?*

The Week 13 prompt was intended to encourage a more detailed response:

> *Write a brief story that shows what an engineer does (4-5 sentences). We encourage you to use your intended career for inspiration.*

The convenience sample consisted of 47 participants who had responded to both prompts. This method ensured equal numbers of responses for each prompt, as well as facilitating a pairwise comparison between responses for each participant. If a participant provided two responses to the same prompt, these were considered as two parts of one response.

Data Analysis

We extracted all action verbs, i.e., verbs indicating what an engineer does, from the paired responses. These were identified as any action or process described in each response with contextual relevance to being an engineer or performing the job. Supporting verbs such as "be" or "need" were disregarded. To account for incomplete sentences and various structures, we also included verbs with noun forms. For example, "find solutions to problems" was equivalent to "solve problems," so it was counted as an instance of the verb "solve." All of the responses were also screened for the presence of at least one instance of each action verb. Counts of all forms and conjugations of each action verb were combined (e.g. the count for " solve" also included solves, solution, solving, etc.). We also examined the variation in action verbs, total verb usage, and verbs per response between Week 1 (short description) and Week 13 (short story). Natural Language Toolkit (NLTK) and VerbNet were also used to check for missing items.

In addition, both sets of responses were coded according to the three history-based perspectives identified by Villanueva and Nadelson as follows [6]:

- Mediator: relies upon science, mathematics, technology as tools
- Designer/Tinkerer: invents, designs, solves problems, iterates toward optimal solutions, plans and conducts new processes, any of which may use Mediator's tools
- 21st Century Perspective: builds on Designer/Tinkerer by considering humanistic and social needs, seeks to serve, works on multi-faceted problems in real-world settings

While the designation of Designer/Tinkerer may be viewed as two separate labels, these labels are similar when considering the process of engineering design as involving iteration and re-purposing toward an optimal solution within the available constraints [6]. Our own experience as educators in engineering design project-based courses over many years also provided evidence for design as an iterative and tinkering process.

Since the participants were early college students, we anticipated that their perspectives about engineering would be largely influenced by their education to date, which was compatible with both the academic stage of our students and their relatively low exposure to an engineering or computer workplace. These were the major reason for selecting the coding method used by Villanueva and Nadelson. In addition, the foundation for this method was previously developed and reported by Villanueva in 2015 [18]. The method was also supported by Castillo-Barrera, Amador-Garcia, Perez-Gonzalez & Martinez-Perez, particularly with respect to the use of stories to reveal user preferences in software development [19]. Both the users and the developers in the Castill-Barrera, et.al. study were viewed as similar to many of our students as they were, or as they could be.

The resulting codes were compared to detect differences in perspective between the Week 1 and Week 13 responses for each participant. Since our Week 13 prompt encouraged the participants to write from their own career standpoint, their major was also included in the dataset for comparison to the historical perspectives chosen.

Limitations and Measures of Validity

As a Work in Progress, this study was limited in its institutional space, number of participants, and sampling method, among other factors. Because the surveys were homework assignments, the participants' priorities for devoting time and energy to providing authentic responses may have been affected by commitments to other academic and non-academic activities.

Our attempt to mitigate participation bias was the awarding of participation credit for the surveys as homework assignments. Researcher bias was also possible, because we were unable to employ multiple coders at this stage of the study. However, we used two coding methods in an attempt to triangulate the results.

We can claim content-based evidence or validity on the basis that the study sample and the study population had similar demographics [20]. Similarly, construct-based evidence can be demonstrated by the participants' responses as indicative of early-college impressions of engineering work [20].

Results and Discussion

We identified a total of 59 action verbs in the responses, as shown in Table 1 below. In the Week 1 "Describe" prompt, students overwhelmingly named problem solving and design as key actions of engineers. For the Week 13 "Story" prompt, these two actions were still predominant, but a large number of related actions appeared in at least 20% of the responses. The "story" responses were much longer on average as many students went beyond just adding filler words around "engineers solve problems."

Table 1: Action representations of what engineers do in response to each prompt

	Week 1: Describe	**Week 13: Write a brief story**
Total Action Verbs Represented	23	54
Total Mentions of Actions	100	277
Average Actions Represented	3.06	6.70
StdDev of Actions Represented	1.34	3.18
Average Word Count	14.4	70.1
StdDev Word Count	10.5	27.9

Table 2 contains a list of actions verbs used across all responses, under the conditions indicated below:

Table 2: Actions mentioned by at least 20% of participants in at least one response

Action verb	Describe	Write a brief story
solve (or solution)	77%	54%
design	33%	58%
create	15%	23%
build	8%	25%
test	0%	29%
improve	4%	25%
code	0%	25%
ensure	0%	21%

By applying the historical focus framework, we found that most students described the designer/tinkerer focus of engineering, as indicated in Table 3 below:

Table 3: Percents of Participants in Each Major

	Week 1				**Week 13**			
Major	Mediators	Designer/ Tinkerers	21st Century	Total	Mediators	Designer/ Tinkerers	21st Century	Total
Computer Science	22%	57%	21%	100%	17%	70%	13%	100%
All Engineering	5%	67%	28%	100%	5%	81%	14%	100%
All Others	33.3%	33.3%	33.3%	~100%	33.3%	33.3%	33.3%	~100%

The strong preference that the participants showed for the verbs, "solve" and "design", as shown in Table 2, largely correspond to equally large numbers of both engineers' and computer scientists' responses coded as "designer/tinkerers." This was true for both Week 1 descriptive responses and the Week 13 story responses. In addition, there was a much wider variety of action verb choices in the story responses, which meet our expectation that the story responses would provide richer and more diverse descriptions of what engineers do.

Several of the aforementioned contributors to identity, i.e., **performance, competence, interest, and recognition**, were also incorporated into our methods and results. For example, the concept of **performance** is action-oriented, and we prompted action by asking what an engineer does rather than what an engineer is. Similarly, we addressed **interest** by suggesting that the participants draw from exposure to their engineering or computing specialty. The aspect of **competence** was also implied by the frequent use of the verb "solve", indicating competence in the ability to provide a solution that causes the deficiencies or limitations caused by the problem to cease to exist.

In order to answer our research questions, we conclude that the participants' responses reflected their impressions of engineering based on their educational experiences rather than on experiences in the engineering workplace that might have been gained from an internship or short-term exposure such as a tour. This conclusion is based on the majority of responses containing such general action verbs as "solve" or "design", especially in the Week 1 responses.

Conclusions and Next Steps

One of our next steps is to examine the other parts of speech, to capture the richness and concreteness of the responses. We are also interested in the relatability of the stories, and how concrete examples help first-year students connect with the idea of what an engineer is. This is planned with revised prompts, and the application of natural language processing tools to categorize parts of speech and apply concreteness ratings limited to those with high or low concreteness [14], [15]. This will provide a measure of how real, relatable, specific, and imaginative the responses are.

We also plan to use the responses in an in-class share and discuss exercise, after which we will collect data from students on how well they can imagine themselves doing the things described by their peers. We will also compare these to the historical perspectives of engineering, to examine how well concrete language and storytelling impacts how students view the profession in action.

Another area to explore is that of students' perceptions of what engineers do in terms of how they view the profession vs. how they regard their own work. This comparison could be enhanced by prompts for additional examples and stories. There could be major differences between the views of computer scientist students as opposed to those pursuing the engineering majors. We also plan to conduct this study with first-time-in-college students in their project-based second semester foundations of engineering course. These students will not have declared an engineering major at this stage, although some of them may have already decided which field of engineering to pursue.

Our results can then be used to inform the improvement of our course content to better reflect the reality of engineering work. We also expect to use our results as a starting point for further exploration into specific aspects of imagination-based prompt design to encourage reflective thinking in first-year students about working as an engineer, even as many of them may possess a limited exposure to the everyday realities of the engineering profession.

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