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Perceptions of Undergraduate Mechanical Engineering Students Regarding the True Nature of Engineering Practice

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Introduction

Historical data suggests that only about one in two students initially enrolled in an engineering program at an institution of higher learning will finish that degree program within four to six years [1]. For most engineering programs, regardless of subdiscipline, the first-year curriculum is traditionally comprised of physics, chemistry, and mathematics courses that often fail to inspire students to persist in the program [2]. Students who leave the program frequently report that they came to dislike engineering or became disinterested in the field as a result of their first-year experiences [3]. Thus, a disconnect between incoming students' expectations of engineering and the reality presented during their initial years in the program must be at least part of the attrition problem that has plagued engineering for quite some time. Dissimilar to other well-known professions like medicine and law, there are very few examples of engineering in popular culture, especially considering how frequently other professions appear in the media and various forms of entertainment like movies and television shows. Unfortunately, even fewer of those examples can reasonably be thought of as realistic or authentic, which limits the opportunities for the public—which includes students pursuing engineering degrees—to truly understand and appreciate what engineering actually is.

Not only is engineering as a profession not well understood, the true nature of the practice of engineering is somewhat inscrutable to our enrolled students and sometimes graduates from engineering programs as well. As Sheppard, Colby, Macatangay, and Sullivan (2006) describe, “Engineering practice is not simply a problem-solving process and specialized knowledge. It is the complex, thoughtful and intentional integration of these towards some meaningful end” (p. 435, [4]). Starting in the 1990s, one of the major modifications to engineering education curricula in the United States was the increased emphasis on design as a distinctive element of engineering practice [5]. Most engineering curricula now include at least one capstone design course that introduces the practical side of engineering design to address previous concerns that graduates were unprepared for industry upon completion of an engineering program [6]. However, these courses alone are not facilitating the desired retention gains. They are likely very effective in communicating the basics of the engineering design process but are not able to entirely capture the realities of true engineering practice.

The engineering science courses that occupy much of the middle years of a typical engineering program still tend to employ lecturing and simplified close-ended textbook problems. These teaching strategies are ill-suited for relating the skills and analyses from class to the engineering design process or the engineering profession as a whole. Closed-ended problems usually make assumptions to simplify the problems for students and do not provide them with the opportunity to engage in the kind of decision-making that leads to developing sound engineering judgement [7] [8]. Swenson (2018) found, “Students are aware textbook type problems, a well-defined scenario in which students are solving a problem numerically to find a single answer, are not preparing them for their careers as practicing engineers” (p. 149, [9]). This finding is consistent with other results suggesting a mismatch between the message students receive about engineering practice through their coursework and the reality of engineering practice.

Recent work developing and studying the effects of open-ended modeling problems define an opportunity to provide students with challenging problems that simultaneously reinforce their understanding of course material while exposing them to the realities of engineering practice [7] [8]. Preliminary results from Miel, Swenson, and Johnson (2022) found that "engineering science homework in the form of an open-ended modeling problem can provide opportunities for beginning engineering students to rehearse generating assumptions, revising assumptions, and reasoning about assumptions and their relationships to mathematical equations and models" (p. 15, [10]). Thus, engagement with OEMPs offers a unique opportunity to explore how students' perceptions of engineering science and judgement evolve and whether they recognize the activities as more authentic representations of engineering practice.

This work incorporated two different pedagogies providing contextualization for the true nature of engineering practice into a Mechanical Engineering program at a large Midwest research-intensive university. The first is designed to provide contextualization of engineering practice by introducing students to the history of the profession. The second is intended to provide students with context for how engineering science concepts are implemented in authentic engineering practice and how engineering judgement is essential in that implementation. This paper builds upon previous work [11] to understand how historical and/or technical contextualization of what it means to practice engineering can influence the intentions of students, particularly those identifying as underrepresented minorities and women, to persist in a discipline that historically struggles to retain them. The purpose of this work is to evaluate the reliability and effectiveness of a codebook developed to analyze the responses to an open-ended problem asking undergraduate students to describe their perceptions of engineering practice.

Methods

In the Mechanical Engineering program at a large Midwest research-intensive university, second-year students are required to attend a program seminar intended to educate students about the program and the profession. This seminar has historically been limited to the first third of the semester (approximately five weeks of material) and educated students about different facets of the program such as the required curriculum, technical electives, and various student design groups. The seminar was redesigned in Fall 2023 to include context on engineering as a profession as well as details on how the profession formally started, how subdisciplines of engineering emerged from civil engineering, and the importance of various forms of communication in the profession [12]. Based on student feedback, some of the seminars were revised to be more engaging and efficient in communicating the learning objectives for the Fall 2024 cohort.

During their second year, Mechanical Engineering students are also required to take an engineering dynamics course. Students from other departments like Civil Engineering and Biomedical Engineering enroll in this dynamics course as part of their major. Pursuant to this research, a project has been incorporated into a section of the dynamics course offered in the Spring 2024 semester. For this project, students engage with open-ended modeling problems (OEMPs) during the courses' associated discussion (recitation) sections [7] [13]. While design and lab courses provide students with opportunities to exercise and develop their engineering judgement, OEMPs can be designed to hone this judgement by using engineering science content to make and justify assumptions. For the OEMP integrated into the dynamics course, students work in groups to develop mathematical models that describe a real-world scenario [7] [13], which requires that they employ engineering judgement to make assumptions and simplifications, and to assess the reasonableness of their model and final answer. By placing these projects in the engineering science courses themselves, it aids in helping students to relate that course's content to the engineering design process.

At the end of each semester, students enrolled in the associated courses are invited to participate in a survey, which consists of five Likert-type items regarding their intention to persist and open-ended questions regarding their perceptions of the nature of engineering practice. The open-ended responses were systematically coded to uncover common themes in students' descriptions of their beliefs about the nature of engineering. This paper assesses students' perceptions of engineering practice at the end of the semester. The first author took the lead in iteratively generating the codes for the codebook using the data collected in the Fall 2023 semester. Following feedback gathered from the other two authors as well as from the ASEE community, these codes were revised to be more consistent, and the definitions revised to be clearer. Following these revisions, the codebook was distributed to the other two authors, who then used it to code all open-ended responses collected in the Fall 2023 and Spring 2024 semesters.

To assess inter-rater reliability, interclass coefficients (ICCs) for each of the codes in the revised codebook were calculated. Specifically, the ICC calculations and the corresponding 95% confidence intervals were computed using custom scripts in MATLAB based on a mean-rating ($k = 3$), absolute-agreement, 2-way mixed effects model (i.e., ICC(3,k)). The raters were fixed and evaluated each response provided by the student participants. ICC scores were interpreted via the broadly used guidelines proposed by Koo and Li [14]. Specifically, ICC values that are less than 0.5 are poor, between 0.5 and 0.75 are moderate, between 0.75 and 0.9 are good, and above 0.9 are excellent.

Results and Discussion

Participants: Table 1 below shows the enrollment numbers for the semesters in which the pedagogical interventions have been implemented. The overall response rate across courses for the survey distributed at the end of each semester was 67%. Note that only the open-ended responses from the Fall 2023 and Spring 2024 semesters ($N = 171$) were used to develop the codebook. Data from the Fall 2024 semester is then added in the Preliminary Analysis section of this paper.

Table 1: Enrollments for each semester according to which course is involved in the project.

Semester	Course	Enrollment
Fall 2023	ME Program Seminar	116
Spring 2024	Dynamics	55
Fall 2024	ME Program Seminar	117

Codebook: The revised codebook based on the open-ended question responses collected in Fall 2023 consists of 10 distinct codes that describe students' perceptions of engineering practice:

1. Considers ethics
2. Considers safety
3. Considers efficiency
4. Considers complexity
5. Utilizes knowledge
6. Collaborates with others
7. Improves or makes new designs
8. Solves problems
9. Improves life
10. Expressed personal career aspirations

The first four codes (1-4) are related to relevant factors an engineer incorporates into the early stages of the design process. The next three codes (5-7) are related to how the design process is completed. The next two codes (8-9) are related to the goal of succeeding in the design process. The final code acknowledges that several students conceptualized engineering practice in terms of how they envisioned their future.

Codebook Reliability: The inter-rater reliability of the codebook is reported in Table 2 below. Note that all codes achieved a good or excellent rating (> 0.75) [14].

Table 2: Intraclass coefficients (ICCs) and their associated 95% confidence intervals for each of the 10 codes in the revised codebook. For the confidence intervals, CI-Lo denotes the lower bound and CI-Hi denotes the upper bound. The interpretation (Int.) of the ICC scores is also provided, which were poor (P), moderate (M), good (G), or excellent (E).

	1	2	3	4	5	6	7	8	9	10
CI-Lo	0.88	0.91	0.91	0.68	0.88	0.91	0.81	0.91	0.89	0.70
ICC	0.91	0.93	0.93	0.76	0.91	0.93	0.86	0.93	0.92	0.78
CI-Hi	0.93	0.95	0.95	0.82	0.94	0.95	0.90	0.95	0.94	0.84
Int.	E	E	E	G	E	E	G	E	E	G

Preliminary Analysis: Table 3 shows the results of applying the revised codebook to the data collected for all three semesters. About half of responses from students described engineers as people who solve problems (8), around a third thought engineers should consider ethics (1) and improve life (9), a quarter said engineers should improve or make new designs (7), and a fifth stated that engineers utilize knowledge (5). Note that a response can include more than one code.

Table 3: Percent of responses that contained each of the 10 codes by semester and averaged across semesters.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
FA23	22.1	17.4	12.8	15.1	18.6	10.5	36.0	50.0	33.7	15.1
SP24	29.5	11.4	9.1	6.8	18.2	11.4	20.5	47.7	50.0	15.9
FA24	38.1	20.6	14.3	14.3	23.8	12.7	22.2	49.2	27.0	15.9
Avg.	29.9	16.5	12.1	12.1	20.2	11.5	26.2	49.0	36.9	15.6

The program seminar was updated for Fall 2024 in the hopes that students would report more well-rounded perceptions of engineering practice. More students in Fall 2024 reported that engineers should consider ethics, safety, and efficiency (1-3) and that an engineer utilizes knowledge and collaborates with others (5-6). However, fewer students thought engineers should improve life (9) or improve or make new designs (7). About the same proportion of students reported that engineers should consider complexity (4) and problem solve (8) as well as expressing their own personal career aspirations (10). Interestingly, more students reported engineers should improve life in Spring 2024, the dynamics course, than either of the other two semesters. Figure 1 illustrates the distribution for the number of codes applied to each response.

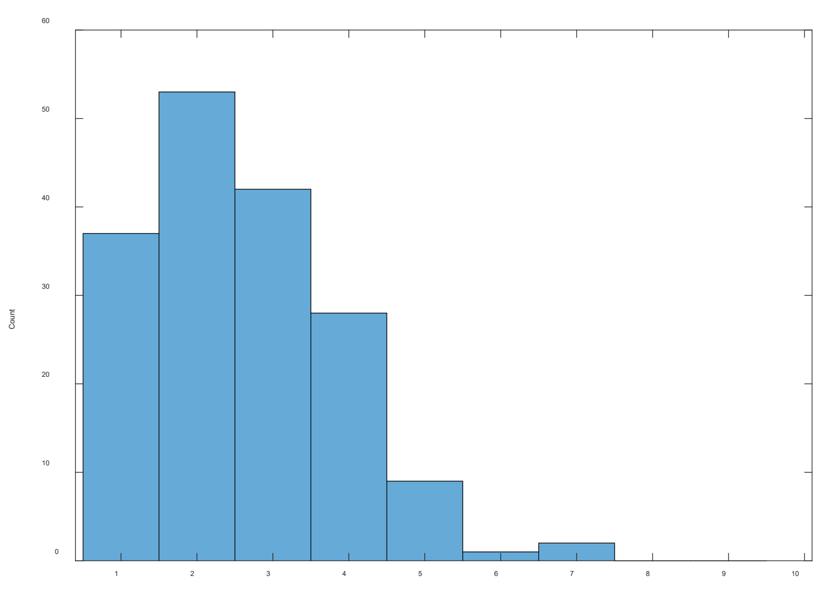

Figure 1: Number of codes applied to each response for all three semesters of responses.

The average number of applied codes per response in Figure 1 is between 2 and 3 codes (2.6), with a maximum of 7. A more complete description of engineering theoretically corresponds with more codes applied. Figure 2 illustrates the distribution for the number of codes applied to each response broken down by semester. It is interesting to note that the responses collected during the program seminar (Fall 2023 and Fall 2024) were on average more detailed than those collected during the dynamics course (Spring 2024). This disparity in the level of detail may partially be attributed to the fact that not all dynamics students had enrolled in the mechanical engineering program seminar. When the responses are categorized based on program seminar enrollment, the average of those who had enrolled in a previous semester was 2.5 codes and the average of those who had not enrolled was 2.1 codes. This difference in the averages suggests that the program seminar may have enhanced students' ability to contextualize engineering practice, thereby fostering more detailed responses.

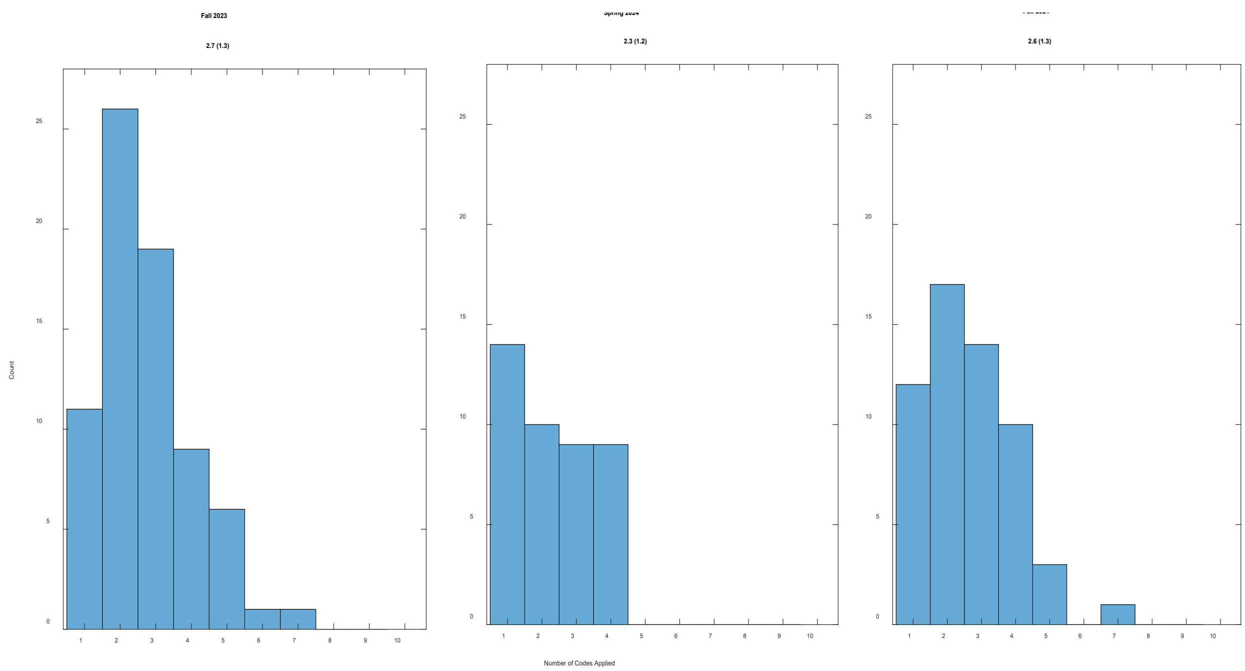

Figure 2: Number of codes applied to each response by semester. The mean (standard deviation) is also offered in the subfigure title as well.

The final analysis focuses on the relationships between the different codes in the form of a network analysis that considers the relationships between nodes (Figure 3). In the figure below, each code is represented by a node. The size of that node is proportional to how many times that code was applied when analyzing the open-ended question responses. As a reminder, the code with the highest frequency was engineers as problem solvers (8) and with the lowest frequency was engineers as collaborators (6). Next, the edges in the graph, or the lines that connect each of the nodes, denote instances when a response included both of those nodes. For example, the thickest edge is the one that connects nodes 8 and 9, which means students most often identify engineers as problem solvers whose overall aim is to improve life or benefit humanity. The next most frequent association was the connection between nodes 8 and 1, which indicates that engineers are problem solvers who have a responsibility to conduct their work ethically.

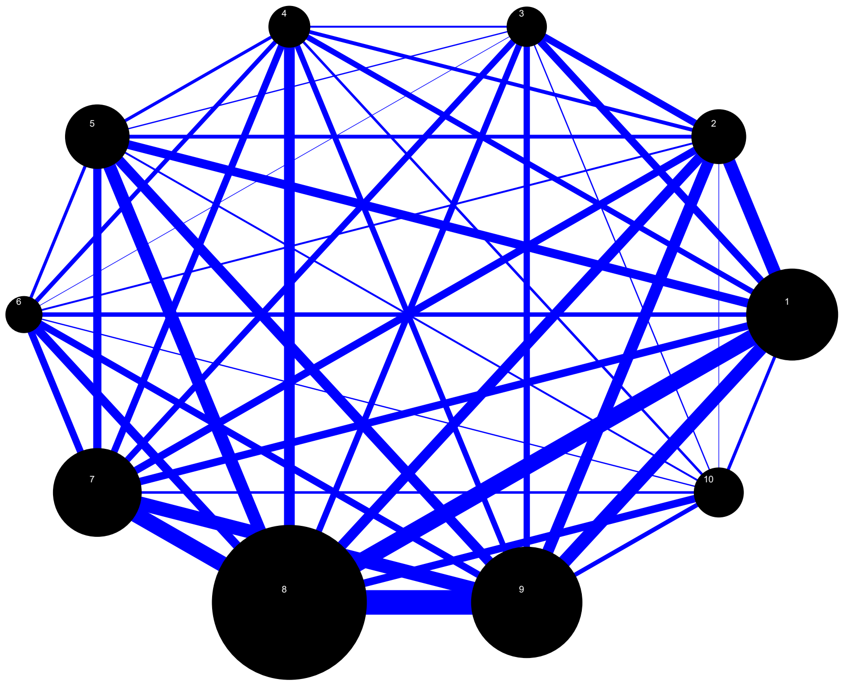

Figure 3: Network analysis for the revised codebook applied to all three semesters' data.

Conclusions and Future Work

While not all codes in the codebook achieved excellent inter-rater reliability, all ten did achieve good reliability. Still, the authors will engage in discussions to come to better consensus regarding the definitions of the codes and potentially introduce new ones to improve the clarity of the codebook. This process will focus on responses in which the authors' coding schemas most disagree with one another. Once this process has been completed, the responses from all three semesters will be re-coded, and the inter-rater reliability will be re-evaluated. While there does not exist a universal definition of engineering, definitions from several sources will be distilled into an overarching definition that will be used to compare against the codes derived from this work. It is unlikely that this definition will contain all the codes in the revised codebook, but it will be useful to know if there are facets of this definition missing from the codebook to begin with.

Other future work includes additional survey data collections as well as conducting and analyzing semi-structured interviews with students who were exposed to one, both, or none of the contextualization interventions. This work will contribute to the research by investigating how students' perceptions of engineering practice develop as they progress through a program, and how contextualizing different educational activities can influence their beliefs and understanding. The semi-structured interviews will provide rich data describing how students' perceptions of engineering practice change over time. The results from this work will be used to guide those interviews as well.

Inviting a larger group of students to participate in the surveys enables this study to draw inferences from a larger sample regarding baseline familiarity with engineering and its potential influence on students' intention to persist in their chosen degree program. This research will provide new insights into students' understanding of engineering practice and how this understanding evolves with exposure to various types of contextualization. It will also illuminate how undergraduate students link engineering science and judgment to engineering practice, particularly in how these elements directly support the design process.

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