How Students Take Up Open-ended, Real World Problems

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***Abstract*— This work-in-progress research paper describes the different ways in which undergraduate engineering students reasoned about the goals of an open-ended problem, and how this influenced the way they solved the problem. Typical homework assigned to students in engineering science courses is often well-defined textbook problems, which are very different from the ill-defined problems professional engineers solve in the workplace. Our research team has been assigning ill-defined problems in introductory engineering science courses in order to give students opportunities to engage in engineering judgement, thereby better preparing them for professional practice. This study examines how students decide to take up an open-ended problem, meaning their sense of the goals of the problem, and how this influences their actions when solving the problem. The results also include an analysis of the reasons students indicated they took up the open-ended problem in different ways.**

Keywords—ill-defined problems, homework problems, modeling, professional practice, undergraduate engineering

I. INTRODUCTION

Typical homework problems in engineering science courses are closed-ended (meaning they have one correct answer) and unlike the complex, ill-defined problems professional engineers solve [1]. Our research team's goals are to develop students' professional engineering skills as they learn canonical mathematical models and conceptual knowledge in courses such as statics, dynamics, and fluid mechanics. The specific professional practice that has been our focus for the past three years is engineering judgement [2]. As defined by Gainsburg, engineering judgement is "using judgement to make a final call on the reasonableness of the analysis or design" (p. 287)[2]. More details of the specific practices this includes can be found in our prior work [3].

In order to give students the opportunity to engage in engineering judgement, students must be assigned open-ended modeling (meaning they do not have a singular correct answer) problems (OEMPs). Our other goals in assigning these "workplace" [1,4] type problems are to have students analyze a real-world object to demonstrate how the knowledge they are learning during their classes can be utilized in a real-world context. While others have designed real-world problems in the past, such as Model Eliciting Activities [5] or case-based problems [6], our problems are designed specifically so students have to engage in engineering judgement by making assumptions, deciding if and how to use a technology tool in their analysis, and assessing the reasonableness of their calculated answer [2,3].

Due to this open-endedness, students inherently make choices about how they go about solving the problem. While some students might approach these problems as any other homework problem, others may shift their approach when completing an OEMP. Past work [7] has shown these choices determine the amount students engage in engineering judgement or other sense-making activities that may lead to increased conceptual understanding. Therefore, we ask:

1. How do students take up open-ended modeling problems?
2. What indicators do we have for why students take up problems in a certain way?

II. BACKGROUND

Our research builds upon the examination of framing and epistemological framing in science and engineering education [8,9,10]. Framing is the expectations one has or their sense of what is going on in or about a situation [11,12]. When a student walks into a classroom they have expectations about what will happen in that room and may indicate those expectations by taking out a notebook and pen and facing the front of the room. Epistemological framing is defined as the "sense of what is taking place with respect to knowledge" (p. 149) [8]. For example, a student has different expectations about how to use their knowledge about gravity depending if they are watching a small child play on a playground or walking into a physics classroom. On a playground, the knowledge you use is that gravity pulls us towards the earth, whereas in a physics classroom you typically need to know gravity is 9.81m/s2 or represented using an arrow pointing down.

Hammer, Elby, and colleagues' [13] work demonstrates how "productive framing" of scientific activities leads to engagement in disciplinary activities such as making sense of scientific phenomena [14] or using research and data to make arguments [15]. Simply, productive framing leads to more authentic scientific thinking. Like these authors' goal of orienting students to authentic scientific activity, our goal is to engage students in disciplinary engineering activities such as making sense of phenomena, creating mathematical models, and engaging in making judgements.

An example of this can be found in McCormick & Hammer’s [9] account of Stella and Alexi, two students in a fourth grade classroom engaged in an engineering task taken from a book they read in their class. The problem given to the students is to design a pen for Shiloh the dog, who has been rescued by Marty from a mean owner and larger dog who both mistreat Shiloh [16]. In this case study, the authors show Stella and Alexi’s prioritization of their client’s needs over the testing parameters set by the classroom. While other students switch between playing classroom games and designing in the context of the story, Stella and Alexi maintain a stable framing in meeting their clients’ needs. The authors argue Stella and Alexi’s framing of their design task this way makes their activity and engagement more disciplinary authentic than their peers.

In this paper we use the phrase taking up instead of epistemological framing because our data comes from retrospective recollections of problem solving. Hammer, Elby, and colleagues note that epistemological framing may change from moment-to-moment [8,17], and the analysis of epistemological framing therefore requires audio or video data collected as students are engaged in the problem. Like Scherr and Hammer [8], we wish to determine how students understood OEMPs “with respect to knowledge, reasoning, and learning” (p. 148) and how they perceived the goals of the activity. Therefore, we define taking up as a student’s sense of the reasoning and goals of the OEMP activity, and how that determined the ways in which the student went about solving the problem. Like the work in physics and engineering education before us, we investigate whether a student’s frame leading more to disciplinary activities such as reasoning about assumptions, assessing how good or precise their calculation is, making sense of a concept they just learned in class, or applying a canonical model to a system properly [2,14,18], or are they just oriented to meeting classroom expectations.

III. Methods

Professors at three universities assigned OEMPs in their statics or mechanics of materials courses: Yellow University, Blue University, and Maroon University. Maroon University also assigned two OEMPs in the dynamics course that followed the statics course, taught by the same professor. At the end of each semester, students were asked to participate in a retrospective interview about how they solved the OEMP. From the students that consented to participate, ten were selected at Yellow University, four were selected at Blue University, and nine at Maroon University, with two students participating both semesters resulting in eleven interviews.

OEMPs are designed around four guiding principles [19]: students analyze a real world system, use the canonical mathematical models they are learning in class [20], solve an ill-defined problem [1], and engage in engineering judgement [2]. Students usually begin solving the problems by creating a free-body or impulse-momentum diagram that requires them to make a number of assumptions. Then, they develop a mathematical model to determine a solution, such as selecting a material, calculating a beam cross section or diameter, determining a safety factory, or solving for a velocity. Students are then asked to consider if their answer is reasonable and justify their answer. The OEMPs students discussed in their interviews included the iWalk 2.0 Hands-free Crutch [7], an airplane wing, a bridge [3,19], a car crash [21], and a student selected system [21].

From an initial analysis examining these interviews for engineering judgement, the research team saw evidence of different framings. We saw instances where students described how solving these problems made them “feel like an engineer.” We also saw instances of students engaging in the classroom game [13,22], trying to complete the assignment with the minimum effort required to earn a sufficient grade. The second author used techniques derived from discourse analysis to identify utterances where students expressed how they viewed their goals during the problem. Once she identified initial utterances, she collected words and phrases that were seen frequently. Common phrases included variations of “good enough” or “close enough,” references to the “right answer” or “correct answer” of the OEMP, and the mention of “bonus points” towards their grade. Other students commonly mentioned phrases such as “practicing the real world” and mentions of different forms of optimization and external research. Some students also directly noted the problem was “applicable” to real life.

In the next step of the analysis the researchers highlighted each piece of data in the transcripts and then combined utterances on a single spreadsheet to aid coding the data. The identification process began with author two openly coding the students’ goals. At the end of this first open identification, authors one and three discussed the categories and determined the best examples and data that matched. Author two re-examined the responses and refined the data based on the new definitions. The final two kinds of taking up and their definitions are found in Table 1. Like Hutchison and Hammer [13], a finer grained analysis may uncover other distinctions but we found two general ways students framed their work; one oriented towards “the classroom game” and the other oriented towards disciplinary authentic activity.

Table I. Taking Up Definitions

Taking Up	Definition
Homework Problems	A student states that they were concerned with what the teacher would think about their work or the grader’s requirements. Students could also state they were not worried about accuracy or if their answer was good enough.”
Engineering Problems	A student states that they were concerned with meeting requirements that were not asked for in the problem including meeting client needs or making something easy to manufacture. Students could also state they went above and did external research to increase the accuracy of their solution.

IV. FINDINGS

In total, we looked at 25 student interviews and found 55 utterances of taking up. The distribution of the instances of taking up are seen below in Table 2.

Based on the analysis outlined in the previous section, we present the following findings: 1) Some students understand they can choose how to solve a problem and some believe it to be "freeing," 2) We see evidence of students taking up the problem as either a homework problem or an engineering problem, and 3) At times, we see evidence of students acknowledging they went between ways of taking up the problem.

A. *Students acknowledge their freedom in how to sole the problem*

As these problems are very open-ended, students inherently have choices about how they solve the problems. In the retrospective interviews, students personally identified the "freedom" they have in solving the problems and attributed it to the nature of the problem. A student from Blue University said, "here I had the freedom and felt completely free to do whatever I wanted, and what I wanted was to get the best out of it." A student from Maroon University expresses a similar sentiment saying, "We're not just given a homework assignment. We have a lot more freedom when we're solving this problem." Across the three universities interviewed, there were nineteen utterances of students mentioning how they felt "free" or unrestricted by the assignment.

B. *Students take up the problem as an assignment*

We have determined that when students take up the OEMP as a homework problem they are only oriented towards meeting the expectations of the professor or earning extra credit points. Students also stated they were not worried about the accuracy, or how close their solution is to their idea of a "correct answer", or if their answer was "good enough." When considering the assumptions of the model, some students were observed to not be worried about the accuracy of their final solution. For example, a student from Maroon University said, "I didn't really state why I simplified some things, which I probably should have, but I still think it was good enough because I was able to estimate things and then just use the information they gave me to produce all these answers that they wanted."

Due to the overall workload of their academic schedule, some students did not do "what made sense" in their model. We interpret that to mean that the student maybe took a shortcut to a solution, one that would not be allowed while solving a real engineering problem at a company. A student at Blue University said that lack of time is to blame. The student states, "we didn't have enough time to recalculate all of our forces, so instead of doing something like that, which would have made more sense, we just kind of averaged all of the values we got for the forces, which doesn't seem like it makes too much sense."

TABLE I. INSTANCES OF TAKE UP FOR EACH INTERVIEW

University	Student Pseudonym	As a Homework Problem	As an Engineering Problem
Maroon University (Statics, Semester 1)	Adam	0	0
	Lane	0	3
	Larry	4	0
	Cristina	0	1
	Dylan	0	0
	Geoffrey	1	0
	Rich	2	0
Maroon University (Dynamics, Semester 2)	Cristina	2	0
	Lane	0	1
	007	0	2
	Joe Wong	1	1
Blue University (Statics)	Student 1	2	0
	Student 2	2	1
	Student 3	1	4
	Student 4	2	0
Yellow University (Statics)	Ghost	1	2
	Grant	0	0
	Rick	2	2
	Chester	2	0
	Ross	0	1
	Sean	4	2
	Broderick	1	2
	Hank	0	2
	Henry	2	2
	Oliver	0	0

C. *Students take up the problem as an engineering task*

In the other cases, we see students making decisions based on design metrics that were not explicitly required by the OEMP assignment, such as being usable for a client or easy to manufacture. We believe in these cases that the students are taking the problem up as a real engineering task. Some students wanted to find the best answer through iterative design or optimization, without being asked in the question. As a student from Maroon University said, "I just kind of use those assumptions to build a model and then I would just kind of test that model and things that didn't work, I would be like ok 'I'm going to fix that and change that."

Other students were concerned about how the client that would use the product, despite it not being a requirement or mentioned in the problem statement. As a student from Blue University said, "I knew for sure aluminum would be a realistic material at the time and it could have been steel, but also like, I was thinking from a price perspective, corrosion, a lot of things that the people might go through while using iWalk, so I said it was aluminum."

We also determined that students concerned about the manufacturability of the model also fell into this category. Each OEMP had different considerations, but students that considered the ease of manufacturing without being prompted were considered to be doing a real engineering task. As a student from Yellow University shares about the beam problem, "I did just a square [beam cross section] and that's pretty easy to manufacture and ship."

D. *Students acknowledge making choices in how to take up*

While the previous two sections discuss the two ways of taking up an OEMP separately, it is important to note that students were not observed to be taking up the problem exclusively as either a homework or an engineering problem. These two ways of taking up were seen to overlap for some students as they acknowledged shifting between the two. For example, a student from Yellow University detailed all of the work he did to make his problem realistic to an engineering problem, and then he went on to say that he didn't want to spend any more time on the problem. First this student described everything he considered on the bridge he was modeling including students, professors, and equipment, then said, "I did start looking at references about how to calculate fluttering for bridges and then I realized I didn't want to spend eight hours on one problem."

However, some students were conscious of the ability to make this decision, but chose which they wanted to pursue. These students note that the open-ended nature of the problem allowed them to make a decision of what to prioritize in the problem based on the level of difficulty they wanted. One student at Yellow University said, "I really like these open-ended problems because you can kinda pick your level of complexity." Other students that acknowledged the level of complexity also believed that the end priority of the assignment was to make the model as realistic as possible. This affected how they took up the problem. A student at Maroon University said, "we had, like the choice of how complicated, we had to make it and assumptions and so I took it as like, 'Oh, we have to make it as close to reality as possible.'"

Some other students commented on the fact that external circumstances might have influenced their decision to take up the problem one way. One student noted the exact moment the transition occurred between rejecting the choice to take up a real engineering problem and instead just complete it as a regular assignment. He said it was what his classmates were doing which discouraged him from doing otherwise. This student from Blue University said:

"Cause essentially, by the last day turned into a project, rather than like, an assignment we can learn from which sucks because this...I was really excited to start this open in the project because I've never done one before, but due to timing and how our group work wasn't going about by the end and didn't find it again until we did the group assignment in class. Yeah that's kind of the rundown of what happened." […] "And when the project turns into an assignment for me, it's no longer exciting to, you know, learn everything from it and gain a lot of experiences from it. It's just like, okay, this is that next thing that needs to just get done."

This student makes the distinction that at first the OEMP was something "we can learn from" to "this is that next thing that needs to just get done," transitioning from what sense-making or knowledge construction to task production [18,23,24].

V. Discussion

Students' recognition of their freedom about how to go about the problem is similar to the agency or epistemic agency seen in studies about authentic disciplinary science activities [15,25]. Similar to the students in these studies, our students have the freedom to do engineering, with opportunities to define parts of the problem, solve them, or even fail to find a reasonable answer [15,25]. Their framing of the activity thus determines the disciplinary authenticity of their engineering task.

Similar to the results in Hutchison and Hammer [13], we see students can take up the problem as a homework assignment or an engineering task. Students who take up the problem as a homework problem do so because they are concerned with the expectations of the teacher, playing "the classroom game" [22], or are not worried about making the problem as accurate to real life as it can be. Students who take up the problem as an engineering task do so to consider aspects that the problem statement did not address including the client that will use the product, the price and ability to manufacture, and the tools like iterative design that real engineers used. We see these students as similar to Stella and Alexi [9], who prioritized the needs of their client in their design over the prescribed tests in their classroom.

Some students also noticed the difference between the frames and we were able to identify multiple transitions between their ways of taking up. It is also worth noting that some students we studied did not adequately express any indications of either taking up that we could gather data and make conclusions from. Our study was limited in that we did not specifically as students how they approached the problem but instead looked for cues in their description of how they went about solving the problem.

The differentiation between these two ways of taking up an OEMP is seen in other research. Teams were seen to move between the two worlds of school and engineering and not exclusively operate in one or the other [23]. Similarly, students in another study saw a distinction between academic problems and "real world" problems [26].

VI. Conclusions and Implications

Some students cited some external reasons for what could potentially limit students from choosing to approach an OEMP as a real engineering problem. This opens up for further research as to how we can identify what is holding back students and how to encourage students to approach every undergraduate assignment as a real-world engineering problem. It is also worth noting that some students we studied did not adequately express any indications of either taking up that we could gather data and make conclusions from. Further research can be done to identify if the teachers' lesson structures have a role in their taking up, as seen in [9]. From the limitations we've seen to taking up an engineering problem, students that are given more time and more knowledge may engage in more real engineering. This also may be possible to increase their use of engineering judgement and improve their experience in the classroom.

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