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BOARD # 427: Preliminary Results of Understanding and Scaffolding the Productive Beginnings of Engineering Judgment in Undergraduate Students (RFE)

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Preliminary Results of Understanding and Scaffolding the Productive Beginnings of Engineering Judgment in Undergraduate Students (RFE)

Abstract

This paper presents the continuation of progress designing, implementing, and assessing the usefulness of open-ended modeling problems (OEMPs) with a focus on scaffolding OEMPs to support students' conceptual understanding of course content and improving the emerging Engineering Modeling Judgment (EMJ) taxonomy. OEMPs are aimed to support the beginnings of engineering judgment in undergraduate engineering students as they apply their intuition, real world experiences, and conceptual knowledge to solve "ill-defined" problems that do not have a single correct answer. Studying how instructors notice student thinking and how students exercise their developing judgments is important as it can help train future instructors to better notice and recognize their own students' thought processes. By scaffolding an OEMP, instructors can provide students with enough assistance to make the problem solvable while allowing students to engage and grapple with the problem in a way that exercises their engineering judgment and improves learning.

Introduction

Throughout the engineering curriculum, students take many engineering science courses [1], [2], [3] such as statics, dynamics, or fluids where the majority of content is presented through closed-ended "textbook" style examples and homework problems. These problems are solved through procedures that use specific equations and have one correct answer [4]. These "textbook" problems make up the bulk of the engineering curriculum, yet they may not prepare students for their future work as engineers after graduation [1], [2], [5]. Ethnographic studies of working engineers show that these professionals typically solve complex, ill-defined problems where the main engineering task is modeling the problem rather than solving a well-defined problem with a single solution [6], [7], [8], [9]. In order to develop these mathematical models of real-world problems, the professional must use their engineering judgment to make decisions. In order to begin developing these skills, engineering students must be given multiple opportunities to practice what we call the productive beginnings of engineering judgment [10], [11], [12] throughout their undergraduate engineering curriculum. This requires that instructors place students in situations where they must model problems with open-ended requirements that can lead to multiple feasible solutions, similar to what they will face in their future engineering jobs.

Our multi-institution collaborative team is funded by the NSF Research in the Formation of Engineers program. Through our design-based research, we explore assignment scaffolding and its effects on student thinking and teacher noticing while students solve open-ended modeling problems (OEMPs). Our previous work focused on student thinking, and our focus this year has shifted to the *scaffolding* of the OEMP. Scaffolding provides structure that allows a student to perform tasks that would otherwise be overwhelming [4], [13] so that students can focus on developing the productive beginnings of engineering judgment. We are looking at two types of scaffolding: *planned scaffolding*, written into the assignment materials, and *interactional scaffolding*, ad hoc scaffolding through communication between students and instructor [14]. The first research question of our overarching project addresses student thinking, whereas our second and third questions address scaffolding:

(RQ1) In what ways do undergraduate engineering students display the productive beginnings of engineering judgment?
(RQ2) What assignment scaffolding supports students in developing the productive beginnings of engineering judgment?
(RQ3) What assignment scaffolding makes students' productive beginnings of engineering judgment (or lack thereof) visible to instructors?

Prior Work

This paper continues the work done by the fourth and fifth authors to design, implement, and evaluate OEMPs [15], [16], [17], [18], [19], [20], [21]. This work builds off of Gainsburg's identification of eight categories that make up engineering judgment [8], [15], [22]. As an extension and transformation of Gainsburg's categories, we developed the emerging Engineering Modeling Judgment (EMJ) taxonomy which identifies 4 distinct types of engineering judgment, with 15 total subtypes [15], [21], [22], [23], [24]. This taxonomy was developed from iterative coding of data from interviews of 34 students who completed an OEMP in their statics and mechanics of materials courses [22]. This prior work addresses RQ1 of the project.

Our previous work also described evidence-based scaffolding considerations for OEMPs: breaking an open-ended problem into multiple parts, assigning an open-ended problem soon after relevant topics or skills are taught in class, frequently reassuring students that there are multiple solutions to one problem, providing students multiple opportunities for receiving feedback, recognizing that different students may have positive and negative experiences working on open-ended problems in a group, and recognizing that different students may enjoy and struggle with the open-endedness of the problems [17], [19], [25], [26].

Current Work

To begin answering RQ2, we investigated planned scaffolding by interviewing a professor who designed a pool lift-themed OEMP and analyzing the written scaffolding to identify where students were expected to use engineering judgment and apply specific statics concepts. The pool lift assignment is split into six parts where students gradually design and mathematically model parts of a portable pool lift's linkage and base in alignment with statics concepts taught throughout the semester. After analyzing the written scaffolding, we reviewed a video transcript of collaborative work sessions from a group of students as they worked through the OEMP to determine whether the students demonstrated engineering judgment and correctly applied the statics concepts identified in the scaffolding analysis. The results demonstrated that the pool lift scaffolding was generally effective, however, instances of overly direct scaffolding appeared to inhibit students' use of engineering judgment [14].

We then collected data in Fall of 2024 and Spring 2025 on the interactional scaffolding from the same professor interviewed for [14], an additional professor, and a graduate teaching assistant while they assigned and facilitated the pool lift OEMP in statics. The data include observational field notes and audio recordings of the instructor's presentation of the six project parts in lecture or recitation, interactions with small groups as they asked questions and submitted design report (DR) forms, end-of-semester interviews with ten students, and copies of DR forms from interviewed students. After each project part submission, we held a brief ad hoc interview with each instructor to reflect on common themes that they noticed as they were helping students. The observations and interviews from Fall 2024 are currently being analyzed. Preliminary results show tools that the instructor uses to scaffold student thinking (e.g. guiding questions, real world example, walkthrough) and judgment skills that the instructor is scaffolding (e.g. designing with judgment, assessing reasonableness, reflecting on decisions/results). We also saw student conceptual misunderstandings that the professor must scaffold and correct to effectively model the pool lift. Surprisingly, some of the most common conceptual misunderstandings are not newly learned statics concepts, but rather basic trigonometry, mathematical sign errors, or MATLAB coding. In an ad hoc interview, the professor noted that it is especially important to help students to successfully complete each section of the OEMP before moving on to the next to avoid compounding errors that inhibit student learning and reduce the ability of the instructor to provide effective help on future sections.

To begin answering RQ3, we interviewed five faculty members who had previously worked with the research team to design and implement OEMPs in at least one of their courses. During the interviews, instructors provided context and background for the course, stated their motivation for implementing the OEMP, and discussed the ways in which they noticed their students' emerging engineering judgment. Toward the end of the interview, we presented the EMJ Taxonomy and asked the interviewee to comment on the degree to which the taxonomy captures their experiences with the OEMP. We examined the interviews to identify how the instructors noticed student thinking during their OEMP. From our initial analysis, the instructors were able to recall noticing multiple aspects of student thinking as they completed the OEMP. When presented with the EMJ Taxonomy, they gave specific examples of how students had engaged in all four types of emerging engineering modeling judgment. One interviewee described how their students' emerging judgment extended further than the taxonomy. Furthermore, some instructors noted how the OEMP scaffolding explicitly asked students to engage in some types of emerging judgment. While there was no specific question about the personal qualities that helped students to be successful on the OEMP, four instructors discussed this in their interviews. They noted that successful students had the qualities of creativity, maturity, failure tolerance, and self-efficacy. Instructors also commented on the methods they used to assess student thinking throughout the OEMP. This included, but was not limited to: 1) observing and advising student groups in class, in office hours, and via email; 2) requiring students to meet with them to informally discuss their initial progress; 3) reviewing student-created logbooks that documented all aspects of their problem-solving process; 4) engaging other members of the instructional staff; and 5) assigning a reflection on their process of solving the OEMP. The instructors also differed about whether or not they would provide their students with the EMJ Taxonomy. One instructor said they would not, another said they would give it to students before the OEMP as an example of good and bad behavior, and a third said they would reflect on the taxonomy with students after the OEMP.

Conclusions and Future Work

In the coming months, we will continue to analyze the interactional scaffolding data that were collected during the 2024-2025 school year in order to answer RQ2. Studying these courses will allow us to further investigate the ways in which instructors scaffold engineering judgment in open-ended modeling problems to answer RQ2. We will also continue to analyze the faculty interview data that we collected to answer RQ3. We also plan to develop "video clubs" in which faculty meet with a member of the research team and watch recordings of students engaging in an OEMP and describe the aspects of engineering judgment that they notice [27]. This work will help us to better understand how instructors develop their ability to notice engineering judgment, and help us to identify the particular aspects of OEMP scaffolding that make students' engineering judgment visible.

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