Open-ended Modelling Problems

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Abstract

This Practice Paper conversation describes the intentions, learning objectives, guidelines for problem design, and best practices for implementing Open-ended Modelling problems (OEMPs). OEMPs are ill-defined mathematical modelling problems assigned in the technical core engineering courses with the goal of engaging students in the practice of engineering judgment. This collaborative project, started in 2018, includes engineering education researchers studying student learning and practices and instructors iterating on problem design and implementation. While a significant amount of our project work focuses on students' learning and thinking, this paper is designed for engineering faculty interested in implementing similar problems within their classes.

Keywords: engineering judgment, complex problems, problem solving

1 Introduction

Graduating engineers need to be able to solve complex, ill-defined problems that are measured by non-technical metrics (Jonassen, 2014; Jonassen et al., 2006). While many design courses in the engineering curriculum ask students to solve complex problems, few engineering science courses, or courses based around learning mathematical models, assign problems where there are many justifiable solutions. Instead, engineering science courses typically assign well-constrained problems that have one correct answer. While these types of homework problems build technical ability, they do not build ability to make justified decisions or practice engineering judgment.

Our project aims to better prepare students for industry engineering work by giving them the opportunity to engage in making judgments while modeling or designing an engineering system. Over the last six years we have worked with faculty teaching statics, mechanics of materials, dynamics, fluid mechanics, advanced aerospace structures, and road vehicle dynamics to implement Open-Ended Modeling Problems (OEMPs).

2 Background

Engineering judgment, or informed decision making in engineering (Davis, 2012; Marr, 2006; Peck, 1991; Vick, 2002), is used when analyzing or predicting the behavior of systems, designing components or structures, or deciding how and when to use theories or canonical models (Edmondson & Sherratt, 2022; Peck, 1991; Vick, 2002). In literature, judgment is equated to expertise; the more an engineer practices engineering the greater ability and skill they have in making judgments. Our project seeks to understand how the ability to make judgments within engineering begins as well as providing an opportunity for students to develop judgment and problem-solving skills. To study this, we developed OEMPs to give students the opportunity to make judgments.

Our project aims to understand what kinds of judgment students engage in when given an OEMP, and how professors design and scaffold problems and notice students' practices of engineering judgment. This paper aims to share our innovative problem type and provide an overview of how our research team designs, assigns, and facilitates these problems in engineering classrooms.

3 Learning Objectives

The project began with four intentions for student engagement. Our research team believes that student learning is built off of their prior experiences both inside and outside of the classroom (Belenky et al., 1986; Bransford, 2000; Piaget & Inhelder, 1969; Vygotsky, 1978). Therefore, our first learning objective is to build links between students' real-life experiences and the engineering science content that they are learning in the classroom. In my prior work (Swenson, 2018), mechanical engineering students reflecting about their courses described wanting to see more connections between what they were learning in the classroom and the real-world, which became an inspiration and goal of this work.

Second, students needed practice solving problems that had no “correct” answer (Jonassen, 2014; Jonassen et al., 2006), meaning problems that did not have an answer in the back of the book for students to try to match. My dissertation research on fluid mechanics and controls homework problems showed that many students were engaged in task production when doing their homework problems, meaning they were focused on getting through the task and finding the answer that matched the back of the book instead of learning the content of the course (Koretsky et al., 2014; Swenson, 2018). In physics education, researchers have written about students playing the “classroom game” (Hutchison & Hammer, 2010; Lemke, 1990) and our objective was to reduce this behavior.

Third, it was important to my collaborator and myself that students would continue to use and practice the canonical mathematical models taught in the courses in which they were enrolled (Gainsburg, 2013; Johnson & Swenson, 2019). A significant part of the OEMP is deciding which mathematical model or series of equations to use to model the system assigned which gives students additional practice.

Lastly, we wanted students to practice engineering judgment (Gainsburg, 2007; Swenson et al., 2025). Students are not explicitly taught judgment as part of the OEMPs. Instead, our project aimed to understand the productive beginnings, or emergence of disciplinary practices, of judgment. Over the first four years of the project, we analyzed the interviews of 34 students solving OEMPs in mechanics of materials or statics courses. We identified four types of judgment and fifteen justifications (Swenson et al., 2019, 2022, 2025) that students self-reported engaging in while solving one or two OEMPs, shown below in Table 1. The four major types of judgment we found are: making assumptions, assessing reasonableness, overriding a calculated answer, and using technology tools.

Table 1. Engineering modeling judgment (EMJ) taxonomy (Swenson et al., 2025)

EMJ 1 Making Assumptions	
EMJ 1a	Making an assumption with no justification
EMJ 1b	Assumption considers the user, client, or manufacturer
EMJ 1c	Assumption makes the model more realistic, accurate, or typical based on the student’s research or experimentation for the class
EMJ 1d	Assumption makes the model more realistic, accurate, representative, or typical based on the student’s personal lived experience outside the classroom
EMJ 1e	Assumption makes the model solvable
EMJ 1f	Assumption makes the model easier to solve and/or simplifies the model
EMJ 1g	Assumption does not affect the output of the model
EMJ 1h	Assumption models what the student thinks is the worst-case scenario
EMJ 2 Assessing Reasonableness	
EMJ 2a	Assessing the reasonableness of assumptions that the student made
EMJ 2b	Assessing the reasonableness of the output of the model
EMJ 2c	Assessing the reasonableness of the model as provided by the instructor in the problem
EMJ 3 Overriding a calculated answer	
EMJ 3a	Overriding a calculated answer with no justification
EMJ 3b	Overriding a calculated answer considering the user, client, manufacturer, or safety
EMJ 4 Using Technology Tools	
EMJ 4a	Using a technology tool to help with analysis or computation
EMJ 4b	Assessing their use of the technology tool

In addition to these four objectives, our faculty collaborators aim for students to engage in the outcomes outlined in ABET, the United States organization that accredits engineering programs (ABET, 2023). Outcomes met by solving an assigned OEMP could include:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. An ability to communicate effectively with a range of audiences
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

Our forthcoming article provides a more detailed explanation of how the Pool Lift OEMP satisfies the above outcomes (Charakos et al., in preparation).

In addition to the above learning objectives, the faculty who have designed OEMPs were interviewed and identified objectives that they had when designing their OEMP. Besides wanting their students to learn engineering science concepts, faculty also wanted their students to understand the nature of engineering problems and engineering problem solving, learn engineering reasoning, and build emotional skills to thrive in learning and doing engineering (Miel & Swenson, in review).

4 Problem Design

When designing an OEMP, the first two major considerations are choosing the canonical mathematical models you want your students to utilize and practice when solving the problem and the real-world object that they will design or analyse. In the past, our faculty have chosen objects that students may have encountered but not used every day. These include the iWalk hands free crutch (statics)(Treadway et al., 2021), a knee scooter (statics), a pool lift (statics)(Churakos et al., 2024), a hobby aircraft located in the main aerospace engineering building on campus (mechanics of materials)(Swenson et al., 2020), aircraft found in museums (advanced aerospace structures)(Merrett et al., 2023), a washing machine (dynamics)(Vitali et al., 2022), and a skating spin (dynamics)(Vitali et al., 2022). Other OEMP authors have created fictionalized scenarios such as a bridge between two buildings on campus (mechanics of materials) (Johnson & Swenson, 2019) or an underground pipe system connecting a lake with a greenhouse (fluid mechanics). Details about each of the problems can be found in the cited works.

Figure 1: Previously designed OEMP systems assigned to students in statics and dynamics.

When initially outlining the problem, faculty need to consider which pieces of the problem to leave open-ended and where students will have to make judgments. First- and second-year students may need more knowns or given assumptions than upper-level students who have more experience with ill-defined problems. For example, in the pool lift problem students are given a short list of assumptions in the assignment. Yet, students have many decisions to make including the weight of the person, the material, and the dimensions (Churakos et al., 2024). This is where students need to make the most assumptions to move forward in the project and justify their decisions using research, personal experiences, and considering the user or manufacturer (Swenson et al., 2022, 2025).

Another decision the instructor must make is how many pieces of the problem will be completed individually or in groups. Allowing students to complete early pieces of the OEMP individually and then in a group has been found in some cases to build competence with the mathematical models, as the students complete the problem twice. Having students' complete pieces individually also demonstrates to students the many ways the problem can be solved, or decisions can be justified.

Naturally, instructors also need to decide the length of the assignment. Many of the instructors assign an OEMP towards the end of the semester when students have more conceptual knowledge in the course topic. These OEMPs are typically assigned over two or three weeks (Treadway et al., 2021; Vitali et al., 2022). The pool lift problem is assigned over the duration of the entire semester and builds throughout the semester alongside the content of the course (Churakos et al., 2024).

Lastly, we suggest having the OEMP reviewed by other faculty members who have created and assigned similar problems. We have created a community of practice (Lave & Wenger, 1991; Swenson, Rola, et al., 2021) to support other faculty designing and implementing the problems and have found that collaborative review has helped many faculty test and revise their assignment design.

5 Implementing an OEMP

Over the course of six years of designing, assigning, collecting data, and interviewing students about OEMPs, our team has determined several implementation best practices (Swenson, Rola, et al., 2021).

First, instructors have found it helpful to assign pieces of the OEMP very near to when the topic or skill is taught in the course. Many times, the OEMP provides a second avenue for practice with concepts after students complete more traditional homework.

Second, we have found that it is very important to break the problem into pieces and if there is time, allow students to get feedback (Treadway, et al., 2021). Breaking the problem into pieces is first and foremost helpful for procrastinating students, as successful learning from doing these problems does not happen the night before the assignment is due. Having students complete initial assumption making and allowing them to either get feedback from the professor or comparing with other students provides a check on some unreasonable assumptions. In some cases, faculty have created spreadsheets for students to compare their answers to each other, invited students to discuss their results in class, or provided ungraded professor feedback (Treadway et al., 2021). The iWalk problem is assessed in three parts: an individual assignment to create the free body diagram, an individual assessment of the frame analysis, and an assessment of the group assignment when the model is complete.

The instructor of the pool lift problem, which has five parts and a final report (Churakos et al., 2024), has a design review process where student groups are assessed every few weeks. The faculty member runs a prepared MatLab code to check the students' numbers and then provides feedback to students and helps them eliminate any poor assumptions or mathematical errors that may create a flawed design. These mini-check-ins function as student assessments and allow the faculty member to monitor where students are conceptually falling behind. Breaking into pieces and allowing for feedback can also take pressure off of students by knowing they don't have to have the "right" answer the first time and can fix any errors.

Third, students can be very uncomfortable that the problem does not have a single correct answer or that they must make justified decisions. Numerous faculty have reported students coming to them to seek validation or indication that their answer is correct. In retrospective interviews with students after they solved an OEMP, we noticed that the newness of making assumptions caused students to have numerous negative emotions due to the uncertainty of not having a correct answer but also pride and accomplishment from finishing these problems (Swenson, Treadway, et al., 2021; Swenson et al., 2024). Since then, we have further investigated student emotions, or epistemic affect, when solving OEMPs and how students regulated these negative emotions (Swenson et al., 2024). We suggest reminding students at the beginning and throughout the problem-solving process that negative emotions such as confusion and frustration are normal. Encourage emotional regulation strategies such as talking to or comparing answers with classmates or going to office hours (Swenson et al., 2024). Discuss with the students how the skills that they are developing by solving the problem will help them in their engineering careers so they can see value in the struggle. Recognize their accomplishment by building in course-wide celebrations (Maykish et al., 2024). In our examination of emotions, we also saw hints that the feelings of pride and accomplishment also contributed to students' engineering identity or feeling like an engineer (Swenson et al., 2023, 2024).

One way to lessen students' stress or anxiety is to provide rubrics to students that show how they will be graded. In most cases, our faculty grade OEMPs for well-designed and justified mathematical models. For example, the pool lift (Churakos et al., 2024) design reviews include check boxes in which students earn points for well-designed and justified answers. If students make errors, such as if their pool lift would tip into the water, the instructor allows them to revise their work and try again to earn the points.

6 Conclusions

This practice paper conversation detailed the learning objectives and best implementation practices as found by instructors and researchers who design and study OEMPs. Over the course of the six-year project, we have seen students successfully engage in engineering judgment, emotional regulation, mathematical modeling, and teamwork while creating a mathematical model of a real-world system. Currently, our team continues to work with faculty to study the ways in which instructors scaffold problems and notice and respond to students' use of judgment. We invite any interested faculty to join our community of practice and collaborate with our team.

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