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Open-Ended Modeling Group Projects in Introductory Statics and Dynamics Courses

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Traditionally, the types of problems that students see in their introductory statics and dynamics courses are well-structured textbook problems with a single solution [1]. These types of questions are often seen by students as being somewhat at-odds with the more "realistic" challenges that they may face in their design or lab courses. Additionally, in the pandemic-necessitated paradigm of emergency online instruction, methods of assessment beyond traditional exams have become more emphasized, both as a way of keeping students engaged by giving the material relevance and of ensuring that the work that they present is their own when so many solutions are available online.

Our research team has been studying engineering judgement [2] the professional practice used to develop mathematical models for design and analysis, in undergraduate engineering science courses. As engineering judgement is almost synonymous with expertise, our research team has been investigating how novice engineering students practice, or develop the productive beginnings [3] of engineering judgement [4-7]. To engage students in the productive beginnings of engineering judgement our team creates and assigns Open-ended Modeling Problems (OEMPs). In these problems, students are faced with an ill-defined problem that requires them to make and justify simplifying assumptions before they can apply the mathematical modeling or analysis tools that they have learned in class. The problems do not have a single correct answer, and students have to reason about what makes their models "good enough" for the problem that they are trying to solve. This paper examines a new implementation of OEMPs through assigning them as group projects. In Spring 2020 as classes moved online, the first author, as the instructor of a first-year statics course, decided to replace an exam by extending an OEMP from a homework assignment into a group project. Based on the perceived success of that implementation and the continuation of online instruction, the same instructor gave (largely) the same group of students two OEMPs in the Fall 2020 semester in their follow-on dynamics course: one as a homework assignment, and one as a project. As we examine the outcomes of the OEMPs in these sequential courses, we ask:

1) When implementing an open-ended, ill-defined problem as a group project, how did students respond to this new and different type of problem?
2) What were the benefits or drawbacks of creating a group project?

Theoretical Framework

In order to arrive at the mathematical models that they use for analysis and design, practicing engineers commonly employ "engineering judgement" to move between the physical system and the simpler modeled system. Gainsburg observed professional structural engineers in order to clarify the concept. Gainsburg [2, pp. 486-487] determined through her observations that instances of engineering judgement "fell into the following categories:

- Determining what is a good or precise enough calculation or estimation
- Making assumptions or simplifications to be the bases of mathematical models
- Overriding mathematically ‘proven’ results
- Determining appropriate uses of technology tools
- Assigning qualitative factors (e.g., soil type) and applicable conditions for selecting formulas
- Overriding official building codes
- Discretizing (grouping elements to reduce the number of types to be designed)
- Determining what elements or conditions were ‘typical’ (representative) for the structure.”

Study Context and Participants

This study followed students at a small private university in the Southern United States through two consecutive required courses: Mechanics I (statics) in Spring 2020, taken by the majority of students during their first year (45 students total between two sections), and Mechanics II (dynamics) in Fall 2020, taken by most students at the start of their second year (35 students total between two sections). In each of these courses, students were assigned OEMPs at several points throughout the semester to supplement their more typical textbook-style problems. Table 1 below summarizes the implementations of the three OEMPs assigned in Mechanics I and II, which are described in more detail in the rest of this section.

Table 1: Summary of OEMPs assigned across two semesters.

Semester	Spring 2020: Mechanics I	Fall 2020: Mechanics II	
Problem	OEMP-1: iWalk	OEMP-2: Car crash	OEMP-3: Various
HW or project?	Mixed	HW	Project
Elements outside class, individual	OEMP-1A (HW); OEMP-1B (Project)	Parts a-d, across three problem sets	Preparation for progress meeting
Elements outside class, group	OEMP-1GROUP (Project)	None	Proposal; progress meeting; memo and presentation prep
Elements in class	Time to work in groups	Discussion	Time to work in groups; Final presentations

In Mechanics I, the students worked on a single open-ended problem over a variety of assignments (OEMP-1). The problem, adapted from the problem reported in [6], asks students to undertake a static analysis of the iWalk 2.0 hands-free crutch [8]. In its original form, the OEMP was a single assignment. In conversations among our research team, the original implementer of the iWalk OEMP shared her experience with the assignment and her belief that students needed more scaffolding to better engage with the assignment. In order to address this, the assignment was broken down into two individual assignments for Mechanics I, to be approached on different homework assignments. The two individual parts were:

1. Rigid body equilibrium analysis to find external forces, requiring students to model the contact with the ground and estimate the loads applied by the user at the instant during the gait cycle where they think the loads will create the most axial loading of the vertical member (OEMP-1A).
2. Structure analysis, requiring students to define joint types, followed by a calculation of axial stress in the main weight-bearing member and subsequent selection of a material and cross-sectional area (OEMP-1B).

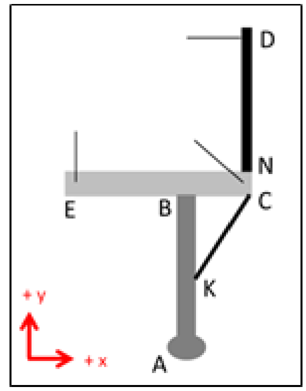

Figure 1: Simplified model of a hands-free crutch

OEMP-1B was originally to be followed by an in-class discussion where students would compare their models and together come to a decision on a “best” model. OEMP-1A was assigned prior to spring break; before the end of break, the university had moved all courses online for the remainder of the semester in response to COVID-19. In response to this shift, the second part was adapted into a project that replaced the third midterm: individuals first completed OEMP-1B described above as an individual portion of the project, and then worked in groups to do the following (OEMP-1GROUP):

1. Work together to combine the best parts of each individual’s models to create the most competent (as judged by the group) model that the group can make.
2. Repeat the calculations and design steps they did in OEMP-1A and OEMP-1B on their new model
3. Then, make an alteration to the model (change a pin joint to a welded joint, calculate for walking on a slope instead of across flat ground, pick a different instant in stance phase, etc.) and re-calculate the axial load in the weight-bearing member.
4. Write a report to explain their work

A total of 10 groups of 3 to 4 students each were assigned for the project based on whether students had provided consent to analyze their written work under the IRB-approved protocol described in the following section.

In Mechanics II, students did two distinct OEMPs: the first (OEMP-2) involved analysis of a car crash based on some crash-scene analysis data, and was assigned across homework assignments in three subsequent weeks. The second (OEMP-3) was a rigid body dynamics group project (with an individual component) with student-proposed topics.

The goal of OEMP-2 was for students to work backwards from an analysis of skid marks left on the road to determine which driver was at fault and whether either driver had been speeding before the crash. The hypothetical crash site was situated at a familiar intersection just offcampus, and students were told that the two cars stuck together completely after crashing. OEMP-2 was broken into parts (a)-(d), assigned across three subsequent homework assignments (A & B were assigned together):

A. Estimate reasonable ranges of parameters for the weight of the two vehicles involved in the crash and the coefficient of friction between the tires and ground, and justify those ranges
B. Use the length of the skid marks and the parameters estimated in part A to estimate the speed v' of the cars just after the collision
C. Use the directions of the skid marks and their answers from A and B to estimate the speed of each vehicle just before the collision (v_a and v_b)
D. Use a provided crash-test report (and/or any other sources) to develop a model of the bumper of the car that hits head-on and estimate its speed before the bumper collapsed, then draw conclusions about fault and who was speeding.

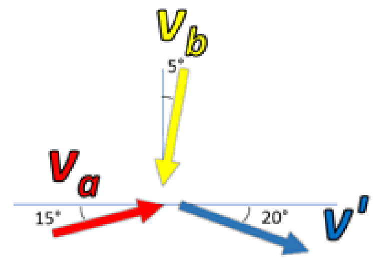

Figure 2: Skid mark angles for car crash

After students had completed parts A-C, they were asked to fill in key assumptions and values on a shared spreadsheet that everyone in the class could see. There was then a brief in-class discussion that revolved around a shared spreadsheet on which students had previously filled out some of their decisions and answers to these parts. This was done to help students develop confidence in their answers or identify where they might have made mistakes by comparing against the work of other students who had made similar assumptions.

OEMP-3 was assigned as a final project in place of a final exam in Mechanics II. Students self-selected groups with between 1 and 4 members, resulting in 13 groups (5 groups of 1, 1 group of 3, and 7 groups of 4). The project was broken into the following parts:

1. Proposal: 1-2 paragraph description of the system to be analyzed with the analysis goal and expected dynamics methods to be applied in analysis. Students were free to select any system they could think of, so long as it could be modeled in 2D with at least one rigid body and the analysis used Newton's 2nd law, Work & Energy, and/or Impulse & Momentum. Feedback was provided to help students achieve a reasonable scope for their group size and clarify their analysis methods.
2. Progress meeting & calculation review: after the group met once to settle on some of their assumptions, each individual was expected to draw free-body and/or impulse-momentum diagrams and set up the equations for the proposed analysis. The group then scheduled a meeting with the instructor outside of class time to discuss each individual's setup, identify errors, and discuss differences in their approaches before the group proceeded to do their final calculations.
3. Final presentation & analysis summary memo: each group gave a brief presentation on their work during the final exam period, and submitted an accompanying memo

containing their problem goal statement, a list of justified assumptions/simplifications, diagrams, calculations, and references.
4. Peer reviews: during the presentation, each individual provided feedback on the clarity of two other groups' presentations

We will focus in this discussion primarily on OEMP-1 and OEMP-3, since those were the problems that had group project aspects to them. OEMP-2 is described mostly for context and to give insight into the level of familiarity that students had with OEMPs before they were asked to propose their own. Most of the students in Mechanics II in Fall 2020 had taken Mechanics I with the same instructor in Spring 2020, and therefore completed all three OEMPs.

Data Collection and Analysis

Research was conducted under a protocol approved by the University at Buffalo IRB, and participants were not compensated. Students were consented separately in both courses and could elect to participate in one or more of the following ways:

1. Allowing analysis of ungraded copies of their written work on OEMPs (Mechanics I: 17/45 students, Mechanics II: 17/35 students)
2. Participation in an interview (Total interviewed in Mechanics I: 6 students, Mechanics II: 4 students)
3. Sharing their final course grade (Mechanics I: 15 students, Mechanics II: 16 students)
4. Anonymous participation in a survey (Mechanics I: 20 students, Mechanics II: 10 students)

Some of the survey questions that students answered in Mechanics II referred specifically to one of the two assigned OEMPs (OEMP-2 or OEMP-3), but many questions were about the two OEMPs taken together. Since the survey was anonymous, individual student responses cannot be correlated to any other data we collected.

Our systematic analysis of the written work and interview transcripts is ongoing; here, we primarily examine the survey results and instructor experience, with limited reference to the interviews.

Findings

Students' comparisons of the OEMPs to their typical homework problems was quite different in Mechanics I and II, as shown in Fig. 3; in Mechanics I, students were also asked about their attitudes towards replacing an exam with an OEMP project. In comparison to textbook homework problems, students were quite mixed in their preferences for OEMPs. However, when asked about the comparison of the OEMP group project to the exam that was initially planned in Mechanics I, the responses skewed more positive.

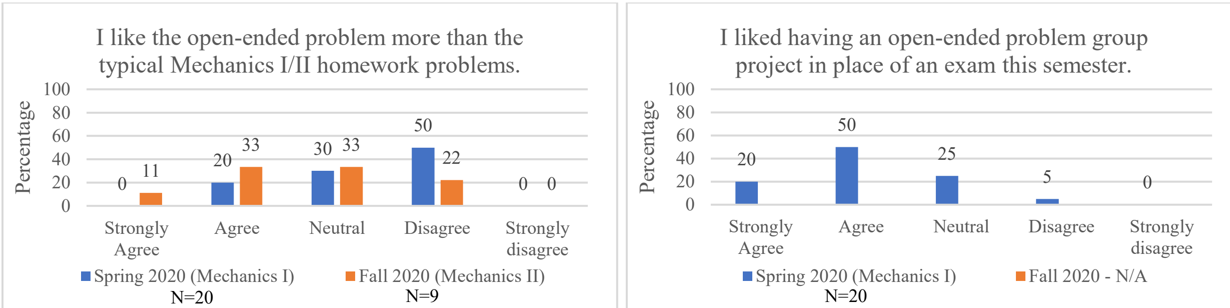

Figure 3: Student comparisons of OEMPs to homework (left) and exams (right). Note that the second question comparing the OEMP to an exam was only asked in Spring, when the transition online inspired mid-semester syllabus revisions.

Despite the somewhat negative comparison to typical homework problems, student attitudes to the OEMPs were generally neutral to positive, and more positive in Mechanics II than in Mechanics I (see Fig. 4). Note that self-selection bias may exist in the survey data, particularly in Mechanics II where a smaller percentage of students elected to participate in the survey.

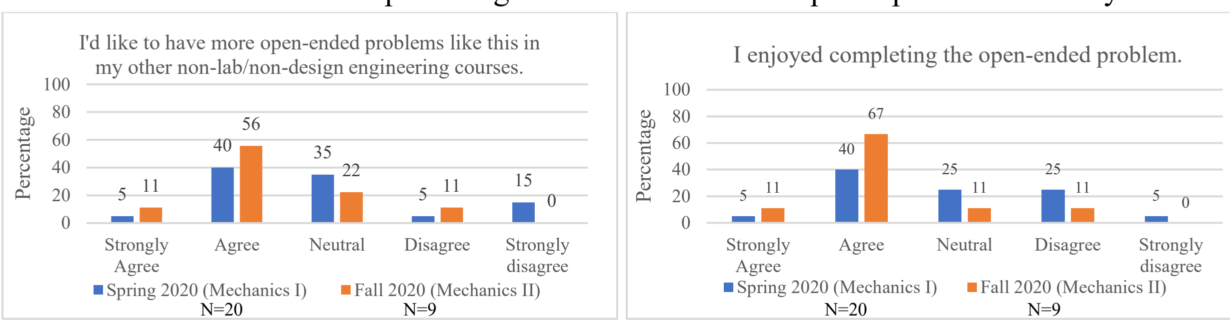

Figure 4: Student attitudes towards OEMPs.

Students' time investment in the projects in both Mechanics I and II was highly variable, as shown in Fig. 5. The reduction in the extremes (0-5 hours and 25-30 hours) in Mechanics II may be related to a more even distribution of work between group members: in Mechanics I, there were two or three groups that had significant interpersonal or teamwork conflicts, while in Mechanics II, no groups brought similar concerns to the attention of the instructor. This may also relate to the improved perceptions of the OEMPs in comparison to typical homework problems that was discussed above.

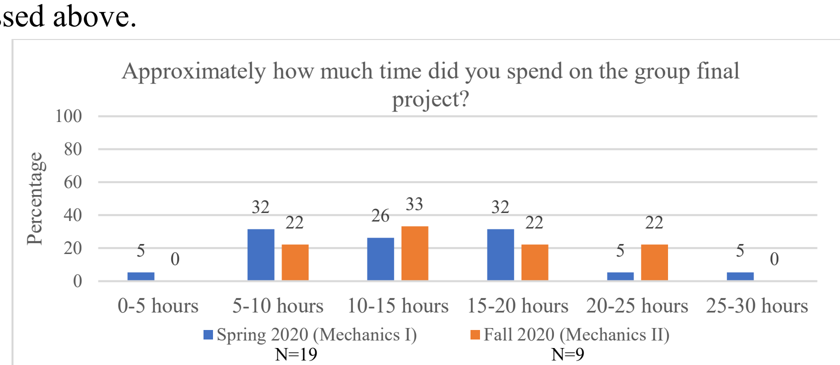

Figure 5: Time spent completing the project.

Practitioner Reflection

From a practitioner standpoint, it was clear that solving the Open-ended Modeling Problems required students to more deeply confront their misunderstandings than a typical exam. OEMP-1 required students to repeat the same rigid body equilibrium and frame analysis multiple times, first individually and subsequently as a group. On the initial individual frame analysis, many students struggled or had significant errors (e.g., missing equal and opposite forces at a joint). However, by re-doing the analysis in a group, most of these errors were eliminated by the final report submission. Perhaps even more telling, at the end of the semester, a poll was given to determine what topics students wanted to review before the final exam; frame analysis was quite low on the list compared to many of the other topics covered after the transition online, suggesting that students felt comfortable with it after doing the project.

Since OEMPs are not the sterilized models presented in textbooks, a related outcome is that students actually have to grapple with static indeterminacy or situations where the approach they are trying to apply does not have enough information. Instructors who assign these problems need to be prepared both to help students who get stuck due to one of these situations and to recognize when students have erroneously reached an answer from a system of equations that should not be possible to solve. For example, in OEMP-1, students who chose the joint at B as a welded joint as opposed to a pin joint and subsequently tried to solve for the forces at each joint found that their equations could not be solved, since the system was statically indeterminate (the moment reaction from a welded joint serves the same function as member CK in preventing rotation about B, except for in the special case in which the resultant force applied to EBC is located directly above B). In OEMP-3, some student groups found that a system that they had initially thought would be simple to analyze had complexities they had not anticipated. As Lane, a student on a team analyzing a zipline, recalled, "So our problem and goal went through a lot of changes, from the beginning to the end. We changed it the day before we presented, because the different goals we had set weren't necessarily ... like he [her group member] couldn't measure that, or he didn't have a problem with that, or it became too complicated."

Scaffolding OEMPs has proven critical to their success based on our team's experiences assigning them in these and other classes. At first, students are deeply uncomfortable with OEMPs that do not have "correct" answers, since these types of problems are very different from what they are typically asked to do in textbook problems. Providing feedback on smaller, more manageable problems helps to build student confidence and let them know whether they are on the right path: OEMP-2 had been previously assigned in Fall 2019 as a single monolithic assignment, and was broken into separate parts as described earlier based on that experience. A single-assignment version of OEMP-1 had been assigned at another institution with similar results, and the division into separate assignments before assignment in Mechanics I seemed to successfully make the problem more tractable for students; the progress meeting served that same purpose for OEMP-3.

The progress meetings were a reasonable way to build individual accountability into the group project for OEMP-3. Since student comments on OEMP-1 revealed frustration with going through the same steps so many times, the progress meeting was introduced as a kind of middle-ground between having no individual accountability and each individual performing the whole analysis before the group worked together. More clarification is needed on the expectations for that meeting, however, since students showed up with a wide range of preparedness, even when provided with the grading rubric. Providing an example is likely the best way to ensure the expectations are understood by all students.

Exposing students to OEMPs across subsequent semesters helped to build their confidence in attacking ambiguous problems. In one of the interviews from Mechanics I, a student justified that her model was a good one because the instructor “didn't give me any negative feedback about it so I thought was okay to use.” By the time we got to OEMP-3, students were much more receptive to the answer to their questions about accuracy being along the lines of “it depends on what you’re assuming,” since the majority of them had already grappled with OEMP-1 and OEMP-2; while they still needed significant guidance sorting through the implications of different assumptions, they were more comfortable with the idea that a certain modeling decision might result in a more or less complex (and more or less accurate/realistic) model, but that this does not necessarily make one choice correct and another incorrect.

Best practices for teamwork tend not to suggest allowing students to self-select their teams [9], and instead encourage instructor-formed teams. However, in a semester where the majority of students were not present on campus and students were working from home in a variety of time zones with varying levels of outside responsibilities and commitments, the flexibility to form groups on their own for OEMP-3 (and to work individually if desired) avoided many of the group conflicts that arose in OEMP-1.

Discussion and Conclusions

Student overall positive attitudes toward the OEMPs from Fall 2020 were largely comparable to previous attitudes in an aerospace mechanics of materials class taught by the third author at the University of Michigan discussed in [5], despite the implementation in [5] as homework projects and our implementation here of a project. Attitudes in Spring 2020 were slightly more negative - while we cannot conclusively say why or how much, it is likely that mid-semester disruption due to the pandemic played some role. Other possible sources of differing satisfaction with the OEMP projects between the fall and spring semesters are (1) the format of the final project; (2) the fact that in the fall, students already knew what was expected of them when assigned an OEMP, which caused less initial anxiety about the open-endedness; (3) the timing of the due date within the semester; and (4) the opportunity to analyze a system of their choice. In the spring, the final project deadline for OEMP-1 was near the end of the semester, about a week and a half before the start of reading days, and the format was a report. In the fall, the OEMP-3 final project deadline was the day of the scheduled final exam, and the format was a presentation accompanied by a memo.

It is unclear how much benefit is derived from enforcing the group aspect of the project. Certainly, groups who participate in serious discussion about the tradeoffs of different assumptions or modeling decisions are more deeply engaged in developing their skills in engineering judgement. However, in an online learning environment, group work challenges are particularly prevalent, with communication and collaboration made harder, even when time is given during class to work together.

While problems similar in nature to OEMP-1 and OEMP-2 would be feasible to assign at universities with large class sizes so long as grading rubrics are implemented and teaching assistants are well trained to handle the types of questions that these problems bring up, a student-proposed project like OEMP-3 would be extremely difficult to implement in a larger class size. Sufficient instructor guidance in setting the scope and approaching each problem was critical to student success. The progress meetings with each group ran between 30 minutes and 1 hour, and a significant number of groups wanted to meet an additional time before the presentation in order to ask questions or get help resolving confusions as they hit roadblocks in their analysis. One group consulted with the instructor no fewer than four times during the week before the presentations. When compared against the time required to write new dynamics problems for online exams and considering the fact that grading the project is faster than grading an exam due to the team nature, this time investment was reasonable for the class size of Mechanics II. Additionally, student attitudes about being able to propose their own projects were extremely positive.

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