BOARD # 443: RIEF: Implementing problem-based learning to facilitate problem abstraction skills in a statics course

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RIEF: Implementing Problem-Based Learning to Facilitate Problem Abstraction Skills in a Statics Course

Abstract

This poster will report on the progress made in the implementation phase of a project funded through the NSF Research Initiation in Engineering Formation (RIEF) program. The project is focused on students' problem-solving skill acquisition in a sophomore level engineering mechanics course (statics) with emphasis on skills related to problem abstraction. The first phase of the project involved planning and development of course materials and research studies. The second phase of the study involved teaching the course using instructional approaches that allow for students to improve their problem abstraction skills through physical models and group problem solving.

Preliminary results show students are engaged: students are explaining their homework problem solutions to peers, working on teams on homework problem sets, manipulating the physical models (with guidance) in class. All students completed team contracts and engaged with their teams effectively to submit assignments. Initial results from graded homework problems indicate that students are confident in their knowledge to complete the problems and in their ability to solve similar problems in the future. Challenges to implementing these instructional approaches include timing of class activities, specifically the amount of time that students took to work with the physical models.

1. Introduction

Statics is one of several sophomore level engineering classes that have high rates of failure (Lord et al. 2017; Min et al., 2011). They are also fundamental to many engineering disciplines, particularly civil, and mechanical engineering. Significant effort has been expended on trying to improve pass rates through: online tools to help students practice drawing free body diagrams; textbooks emphasizing problem solving methods; the use of concept inventories to identify student misconceptions (Steif & Dantzler 2005), and active and problem based learning pedagogy (https://www.handsonmechanics.org/.) However, many of these approaches skip over the initial step of abstraction. That is, the step of taking the real-world problem and describing it in ways that lead to an engineering mechanics problem that can then be analyzed and solved. Instead, pre-abstracted diagrams are presented that students then convert to free-body diagrams to analyze. The diagrams use standard images for different types of connections which, in the worst case, reduces the problem to one of pattern matching when drawing the free body diagram.

The goal of this project is to start with real-world problems, or small physical models of a real-world problem, and teach the students how to abstract the problems into free body diagrams that can then be analyzed. The hypothesis to be tested is that by starting with real-world problems and teaching the abstraction process the students will improve their problem-solving self-efficacy (Bandura 1977, 1986) and make greater connections with their future goals (future-oriented motivation; Miller & Brinkman 2004).

2. Course development and initial delivery

The three-credit statics course was developed in the first year of the project and was delivered by the PI during the first semester of the 2024-25 academic year. The course is taught in the PI's department across multiple sections and has a common topical outline across each section. However, the time spent on each topic, the order, and the method of instruction is left up to the individual instructors. The new version of the course was separated into four distinct modules covering (1) equilibrium at a point, (2) rigid body equilibrium, (3) structural analysis (trusses, frames, and machines), and (4) Internal forces (shear force and bending moment diagrams and second moment of area). The class was designed to be taught in two 75-minute classes each week with a total of 28 class periods, three of which were used for tests.

Grades were based on a combination of group and individual grades. The group work included homework sets, design projects, end of class group formative assessments, and the group submission for each test. Individual grades were for some of the formative assessments, and four tests, one for each module. Each homework assignment was submitted and graded for completeness and then resubmitted and graded for accuracy following feedback during the homework review at the start of each class. A problem-solving process rubric ("PROCESS"; Grigg & Benson 2015) was used for grading homework problems.

The new version of the course was one of 6 sections offered and had an initial enrollment of 44 students out of approximately 240 students taking the class that semester. Of the initial 44 students, 42 completed the course. Student's majors included industrial, environmental, civil, and biosystems engineering and several students who were still in the freshman engineering program. Students ranged from Sophomores to Seniors and were relatively gender balanced. Two of the students identified as having disabilities that required additional time for tests.

While a focused effort had been put into preparing all the materials and class activities, there were still significant adjustments that needed to be made during the semester. Early on, it was clear that class activities were taking much longer than expected. This included both the groups reporting out on the homework and the in-class group problem-solving. This reduced the amount of time spent on discussing the next set of homework problems and on the exit assessment activities. Adjustments were made to reduce the requirements for the homework report-out and developing worksheets to guide students through the in-class activities. It was clear that the rule of thumb for testing, that instructors should allow three times the time it took the instructor to complete the test (Felder & Brent 2016), also holds for in class activities. The first iteration of the class resulted in several lessons being learned. These include:

1. **Active learning takes time.** The PI has used a range of active learning techniques over their nearly 20 years teaching in higher education. However, they had not taught a class that was mostly built around problem-based active learning. As a result there were too many problems planned and not enough time allocated for students to work on them.
2. **Structure is essential.** There was also a lack of structure for some of the activities early in the class that left students unsure of what was expected of them. While problem-based learning typically involves less well-structured problems (Jonassen & Hung, 2008) there is a need for process structure as students adjust to a new class style (Hmelo-Silver, 2004).
3. **Homework problems must be scaffolded.** The goal of the class was to teach students the process of problem abstraction. Therefore, most of the homework problems were built on real-world situations often accompanied by photographs with required information in the problem text. However, students also need to build experience in the calculations that follow the abstraction step. Therefore, some portion of the homework problems may need to be pre-abstracted to provide this opportunity.
4. **Managing everyone's comfort zones is challenging.** The class design was outside the instructor's normal comfort zone and the students' typical class experience. This led to high levels of stress for the instructor and for many of the students (inferred from conversations between the instructor and students outside of class time.) This was particularly difficult when the class got behind schedule due to a natural disaster and adjustments had to be made.

5. **Teaching abstraction is a chicken and egg problem.** One challenge with trying to teach abstraction is deciding, "What do I teach first?" One of the key points of abstraction in statics is deciding how to model the forces that are applied to the object you are analyzing and then drawing the free body diagram. However, without the context of what is next in the analysis process, it can be confusing. For example,looking at the forces holding up a tree branch, students can describe many of the forces, but unless they know that the location and direction of the forces is important, then they can get lost. However, if we start by looking at the set of abstracted connection types (fixed, pin, roller, etc.) and applying them to specific pre-abstracted problems, then students can struggle to extrapolate to un-abstracted situations.
6. **Design projects worked well.** The class included two group design projects. The first was to design the poles and cables for a traffic light system and the second was to design, build, and test a truss bridge using K'nex construction toys. Both projects included a student reflection as part of the submission. The feedback was positive; students provided ideas for new projects and how to refine the existing projects.

The next iteration of the class will be taught in the Fall semester of the 2025-26 academic year. Before then we will restructure the class and make several changes. In particular we will:

1. **Reduce the number of problems in class** - Instead of planning two problems per class we will develop one to two problems per module, giving students more time to reflect on the problem and construct the knowledge needed to solve them. We will also provide more structure during the early modules including using Facts, Learning Issues, Ideas, and Action Plan whiteboard quadrants suggested by Hmelo-Silver [5].
2. **Use more scaffolded homework problems** - The homework sets will be modified to include several simple problems to build confidence in the process before moving on to the more complex problems. However, this will need to be done in such a way as to not circumvent the knowledge construction process inherent in the in-class problem-based active learning. The challenge will be to provide enough opportunities for students to work on problems while giving them the time and mental space to construct the required knowledge.
3. **Focus on facilitator training** - The instructor will spend much of the time before the start of the second iteration of the course learning how to better facilitate problem-based learning. This will include reading about facilitation and observing expert teachers around campus.

3. Research Rationale and Progress to Date

The focus of the research for this project was on examining the extent to which engaging students with real-world problem solving and teaching the abstraction process improves their problem-solving self-efficacy and builds connections between current classroom tasks and their future-oriented motivation towards careers in engineering. In this paper we report on preliminary results related to problem-solving self-efficacy. The preliminary stages of the research involved quantitative assessments of students' problem-solving self-efficacy and students' self-reported assessments of their learning. Specifically, we examined students' self-efficacy for completing problem-solving tasks using a 100-point self-efficacy scale (Bandura, 2006) for each of the problem abstraction steps as defined in the PROCESS rubric (Grigg & Benson, 2015): **P**roblem definition, **R**epresent the problem, **O**rganize Information, **C**alculations, **E**valuate solution (check for accuracy and correct units), **S**olution communication, and **S**elf-assessment.

Survey items asked students to "Please rate how certain you are that you can do each of the things listed below" followed by items such as "Identify constraints, or limits, as given in the problem or by my instructor" and "Draw a visual representation of the information given in the problem." Although the validity and reliability of self-reported self-efficacy data can be questionable for research purposes, students received feedback on these same aspects of problem solving for each homework problem. Such frequent feedback can increase accuracy of self-efficacy assessment (Brown & Burnham, 2012). Students completed this survey about 3 ½ months into the semester, after having completed 19 homework problem sets and 2 exams.

Students' perceptions of what aspects of the course contributed to their learning was assessed using a survey that prompted them to rate their gains in understanding of course concepts. Ffor example, "Represent forces in 2D using vector notation" and "Analyze a truss using the method of joints". They were also asked the extent to which various elements of the course structure contributed to their learning (for example, "Participating in group work during class" and "Working with physical models during class"). Students rated each item on a four-point rating scale ranging from 1 ("no gains" or "no help") to 4 ("great gains" or "great help"). The Perceptions of Learning Gains survey also included open-ended questions about aspects of the course such as "Please comment on how your understanding of the subject has changed as a result of this class" and "Please comment on how the way this class was taught helps you remember key concepts."

We are in the process of cleaning, de-identifying and analyzing survey data collected in Fall 2024, and will be compiling survey data with student performance data to address the research goals of the project. We will also be conducting focus group and individual interviews to further explore students' experiences in the course and connections they are making between working with physical models and their own problem-solving skill development. We will employ a mixed methods approach, combining survey and interview data analyses, to more deeply understand how the instructional approaches taken in this project are perceived by students, the effects of those approaches on students' self-efficacy and future-oriented motivation in engineering, focusing in particular on the use of physical models and team-based activities (e.g., group homework, projects and exams).

4. Conclusions and next steps

The task of explicitly teaching abstraction as part of mechanics problems is challenging for many reasons. The vast majority of existing resources skip this step. The first attempt at teaching abstraction in this project was a limited success. Students did engage in the active learning process and there was positive feedback about the design projects. However, the timing of activities in class and external disruptions meant that we were unable to fully implement the problem based learning approach. Ongoing data analysis of the various survey results will be used to inform refinements to the course delivery and assess the effectiveness of the approach. We will also revisit the survey design to ensure that there are no leading or biased questions, particularly with respect to students' perceived learning gains. We will add focus groups to the research activities in the second iteration of the class.

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