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

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Abstract
This NSF-RIEF project is focused on students' problem-solving skill acquisition in a sophomore level engineering mechanics course (statics) with emphasis on building their problem-solving skills through problem abstraction (simplifying real-world objects into Free Body Diagrams). The first phase of the project involved planning and development of course materials and research studies. This poster will provide a summary of lessons learned in the first two iterations of teaching the course, specifically the use of physical models, shared group explanations of problem framing and solutions, homework problems, test questions, reflection prompts and problem-solving assessment techniques. Teams worked together both in and outside of class on homework problems, design problems, and on the analysis of physical objects. These tasks were designed to improve their problem abstraction and analysis skills as well as developing intuition about how physical systems behave.

Indicators of student learning and the success of instructional approaches used in the course include observations about student engagement in the course activities, student performance on homework problems and tests, students' self-reported confidence in their knowledge and skills, and how well teams are functioning in the team-based approach to problem solving using an established teamwork survey (ITP Metrics). These data were supplemented by focus groups of students in the class. Preliminary results show student engagement is as anticipated: students are explaining their homework problem solutions to peers, working in teams on problems, and manipulating the physical models (with guidance) in class. Initial results from graded homework problems indicate that students are feeling confident in their knowledge to complete the problems and in their ability to solve similar problems in the future.

Keywords: Problem-based learning; statics; instructional methods; problem abstraction.

1. Introduction

Statics is often one of the first undergraduate engineering classes students take. It introduces concepts, such as free body diagrams and static equilibrium, that are fundamental to many fields of engineering. However, statics and other sophomore level engineering classes often have high rates of failure [1,2]. There are many resources available to instructors and students to improve learning such as online tools to guide mastery, concept inventories to identify misconceptions [3] and resources to help instructors undertake active learning in the classroom (e.g. https://www.handsonmechanics.org/ and https://engineeringunleashed.com/). While these are valuable resources, they often skip over the first step in modeling, namely abstracting the physical world into a tractable engineering mechanics problem. Rather, most textbooks begin with simplified drawings of mechanical structures that use standard iconography for various components and connections. A recent study [4] showed that almost all problems in popular statics textbooks are pre-abstracted, highly structured, and algorithmic. This bypasses problem abstraction and risks reducing mechanics to a pattern matching exercise.

The goal of this project is to develop, implement and assess a statics class that explicitly teaches problem abstraction as a precursor to analysis. Many of the problems used in the class are either physical objects that the students analyze or photographs of items that students come into contact with in their daily lives. We hypothesize that, by starting with problem abstraction, students' problem-solving self-efficacy will improve [5,6] and they will make stronger connections with their chosen career (future-oriented motivation; [7]).

2. Course development and delivery

The new course was developed in the 2023-24 academic year and taught in the Fall semester of the 2024-25 and 2025-26 academic years. The first iteration (F24) was taught as a single section out of 6 sections taught by different civil engineering faculty. The semester started with 44 students from industrial, environmental, civil, biosystems, and freshman engineering. The second iteration (F25) had 48 students with the same set of majors as well as materials and biomedical engineering students. In both iterations there were two students who identified as having disabilities that required additional time for tests.

Much of the work during the semester was done in groups. This included design and analysis projects, problem sets, and group tests. After each test was administered to students working alone, the same test was set as a group assignment due a week or so after the test. Groups of four were assigned at the start of the semester by the instructor based on a survey of student availability outside of class. The first group assignment was to develop a group contract to clarify student's individual responsibilities and accountability.

Lessons learned from the first iteration of the class were used to re-develop the course material. Issues identified in the first iteration and addressed in the redevelopment included:

Timing and structure - The first iteration was taught in two 75 minute classes a week. Each class included homework review, active learning, instruction, and discussion of upcoming assignments. This was rushed and did not strike a balance between instruction and active learning. The second iteration was taught in three 50 minute classes a week with classes devoted to instruction, problem solving, and project work.

Scaffolding - The majority of the problems assigned in the first iteration required students to start with abstraction and then move to analysis. This did not allow them to practice the abstraction and analysis portions separately before putting it all together. In the second iteration the problem sets were revised so that, typically, the first 4 questions focused on sub-problems before moving on to more complex fuller problems.

Modeling problem solving - The both iterations of the course adopted the problem-solving "PROCESS" rubric [8]. While this was taught and discussed in the first iteration, it was not consistently modeled during instruction. In the second iteration the PROCESS was explicitly used as the structure for virtually all example problems worked in class by the instructor.

Design problems - The first iteration of the course had two design problems that students worked on. Feedback on these was very positive. In the second iteration more open-ended analysis and design projects were developed.

Managing everyone's comfort zones - The class design for the first iteration was outside the instructor's normal comfort zone and the students' typical class experience. This led to constant adjustments during the semester to adapt to successes and failures in the class. The improved structure and professional development work with the instructor mostly addressed this issue.

3. Problem abstraction

Abstraction herein is defined as the process of taking a real-world system and creating a tractable engineering mechanics problem. This tractability results from reducing and simplifying information from a real system into a system representation (a free-body diagram). Only then, when a system representation is applied to a mathematical model (static equilibrium), is a solution generated. Problem abstraction is therefore distinct from and prior to existing problem constructs, such as complexity and problem-structuredness. Complexity refers to the number of interrelated concepts, equations, and parameters needed to solve a problem. Structuredness relates to how well-defined the problem is, the levels or parameters of uncertainty, and the range of solution paths [9,10].

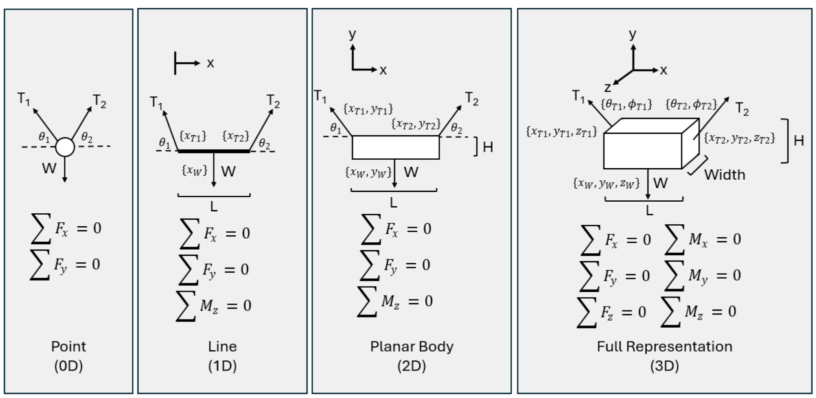

Figure 1. Levels of problem abstraction for an object suspended between two cables.

Complexity is driven by the amount, type, and interrelationship of the information retained after abstraction. Ill-structuredness is a characteristic of systems that have not been sufficiently abstracted. To demonstrate, consider the possible system representations of an object suspended by two cables. See Figure 1. The system is considered more abstract as more information is neglected. Treating a system as a point mass neglects information about the real system, such as the position of the cables and the system's size. For the point mass, very little information about the system is required, and a solution is easier to obtain. Decreasing abstraction (increasing realness) results in a more *complex* system. As for structuredness, different system representations yield different solutions and solution paths. To isolate a single solution (well-structured problems), there are two possibilities. First, the system can be pre-abstracted by the instructor, which removes the range of possible solutions. Second, the desired abstraction process can be indicated by the problem, removing ambiguity about which solution path is appropriate.

One recurring issue in this study was how to abstract particular problems. This often came down to answering the question "how should one model this particular connection between an object and its supports?" While that is often straightforward for experienced engineers, it can be hard for some students to grasp. The larger problem, however, was dealing with statically indeterminate problems as much of the world is statically indeterminate. For example, if you look at a roof truss, it is often nailed or strapped to the building frame. One could debate whether or not that connection should be modelled as fixed or pinned. The bigger issue is that, even if pinned at both ends, the problem remains statically indeterminate. So, while one can teach abstraction, that does not mean that the resulting problem can be solved using the analysis methods taught in a statics class. This meant that certain compromises needed to be made as the class worked on more complex problems later in the semester and some level of pre-abstraction was usually required.

4. Research Methods

The goal of the research is to assess the impact on student's problem-solving self-efficacy and future oriented motivation of teaching problem abstraction and engaging with real-world problems. Student's problem solving self-efficacy was examined using a 100-point self-efficacy scale [11] for each step in the PROCESS rubric [8]: **P**roblem definition, **R**epresent the problem, **O**rganize Information, **C**alculations, **E**valuate solution, **S**olution communication, and **S**elf-assessment. This survey was administered roughly two thirds of the way through the semester. Student groups also reported their confidence in their problem set solutions on each problem throughout the semester.

Future oriented motivation was assessed using a survey developed in previous studies of engineering students' perceptions of their future as related to present tasks [13]. The survey comprises 36 Likert-type items on a scale from 1 to 7, organized by constructs within the Future Time Perspective (FTP) theory [13,14]. These include Perceptions of the Future (students' attitudes towards their future goals in engineering, for example "I am confident about my choice of major"), Perceived Instrumentality (for example, "I will use the information I learn in this engineering course in the future"), and Clarity of Future Goals (for example, "I have a clear idea of what my first job after graduation will be"). Mean scores for each construct (an acceptable practice for Likert-type scales with more than 5 intervals) were compared between Fall 2024 (F24) and Fall 2025 (F25). A survey assessing students' Problem Solving Self-Efficacy (PSSE), with constructs organized based on the PROCESS rubric, was deployed at the end of the semester along with the motivation survey.

Other measures included teamwork assessments using the ITP Metrics tool [15]. This assessment was administered 8 weeks into the 15 week semester and again at the end of the semester. In general groups performed well with only two exceptions. One group was split up part way through the semester of the second iteration. A Student Assessment of Learning Foundation [16] was administered at the start of the semester to assess their perceptions of how prepared they are for this class. This survey also included questions about preferred learning activities. A parallel Student Assessment of Learning Gains (SALG) was administered at the end of the semester.

5. Preliminary Results

5.1. SALF/SALG

Students reported significant learning gains across nearly all statics topics, with 20 of 21 areas showing statistically meaningful improvement and qualitative comments reinforcing deeper conceptual understanding and real-world application in F25. Students' perceptions of beneficial instructional practices also shifted throughout the semester, transitioning from a preference for more lecture-based learning to collaborative, hands-on instruction. Overall, we believe that the redesigned course structure enhanced student learning and engagement.

5.2. Student Motivation and Attitudes in Engineering (MAE):

The MAE survey, which is organized by FTP construct, demonstrated significant gains (p=.007) in Perceived Instrumentality in F25 (n=49) compared to F24 (n=36). No other FTP constructs were significantly different between the two semesters. Clarity of Future Goals continues to be the lowest scoring construct (mean = 4.5/7) and Perceptions of the Future continues to be the highest scoring construct (mean = 6.2/7).

5.3. Student Problem-Solving Self-Efficacy (PSSE):

Individual students' self-efficacy for overall problem solving was significantly higher (p<0.01) in F25 compared to F24, and comparisons of each problem solving task in the PROCESS rubric revealed significant increases in students' reported self-efficacy for all tasks. Student groups' rating of their confidence in their solutions to group homework problems were higher in F25 compared to F24 as well.

5.4. Reflective Group Solution Confidence:

As part of each homework submission, groups would rate their confidence in their solution to each problem and their ability to solve similar problems in the future.. For all 6 items in the survey, there was a statistically significant increase in group problem solving confidence in the second iteration of the course compared to the first iteration.

6. Conclusions and next steps

The task of explicitly teaching abstraction as part of mechanics problems is challenging for many reasons. First, the vast majority of existing resources skip this step. Another major challenge is that the majority of the real-world applications are statically indeterminate. This makes these applications harder to abstract into a problem that can be solved in a statics class. The first attempt at teaching abstraction in this project was a limited success. Lessons learned were used to restructure the class for the second iteration. Throughout the two iterations students engaged in the active learning process and there was positive feedback about the design projects.

Initial results show that the second iteration of the course resulted in clear improvements in many measures of learning gains, problem solving self-efficacy, future oriented motivation, and confidence in their homework solutions. Future work will include benchmarking these data against traditional lecture based course formats and more detailed analysis of the impact of problem abstractness on these measures.

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References

[1] Lord, S., Berger, E., Kellam, N., Ingram, E., Riley, D., Rover, D., Salzman, N., & Sweeney, J. (2017). Talking about a Revolution: Overview of NSF RED Projects. Paper presented at the ASEE Annual Conference and exposition, Columbus, OH.

[2] Min, T., Zhang, G., Long, R. A., Anderson, T. J., & Ohland, M. W. (2011). Nonparametric Survival Analysis of the Loss Rate of Undergraduate Engineering Students. Journal of Engineering Education, 100(2), 349–373.

[3] Steif, P.S. and Dantzler, J.A. (2005), A Statics Concept Inventory: Development and Psychometric Analysis. Journal of Engineering Education, 94: 363-371. ttps://doi.org/10.1002/j.2168-9830.2005.tb00864.x

[4] Therriault, D. J., Douglas, E. P., Buten, E., Bates, E. A., Berry, M. B., & Waisome, J. A. M. (2025). Are there problems with academic problems? Examining problem types in two statics engineering textbooks. European Journal of Engineering Education, 50(4), 764–779. https://doi.org/10.1080/03043797.2025.2459241

[5] Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84, 191-215.

[6] Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice Hall.

[7] Miller, R. B., & Brickman, S. J. (2004). A Model of Future-Oriented Motivation. Educational Psychology Review. 16(1), 9–33. https://doi.org/10.1023/B:EDPR.0000012343.96370.39

[8] Grigg, S., & L. Benson. (2015). Promoting Problem-solving Proficiency in First-year Engineering: PROCESS Assessment. Proceedings of the ASEE 2015 Annual Conference, Seattle, WA.

[9] Jonassen, D.H. Toward a design theory of problem solving. ETR&D 48, 63–85 (2000). https://doi.org/10.1007/BF02300500

[10] Jonassen & Hung (2008) "All problems are not Equal: Implications for Problem-Based Learning" *The Interdisciplinary Journal of Problem-based Learning* **2**(2).

[11] Bandura, A. (2006). Guide for constructing self-efficacy scales. In: *Self-efficacy beliefs of adolescents*. Information Age Publishing; pp. 307–337.

[12] Kirn, A., & Benson. L. (20XX). Engineering Students' Perceptions of the Future: Exploratory Instrument Development, Proceedings of the ASEE 2015 Annual Conference, Seattle, WA.

[13] Benson, L., Bolding, C.J., Ogle, J., McGough, C., Murphy, J. and Lanning, R. (20xx). Engineering Students' Perceptions of Belongingness in Civil Engineering. Proceedings of the 126th American Society for Engineering Education Annual (ASEE) Conference & Exposition, Tampa, FL. (June 16-19, 2019).

[14] Husman, J., & Lens, W. (1999). The role of the future in student motivation. *Educational Psychologist, 34*(2), 113–125. https://doi.org/10.1207/s15326985ep3402

[15] O'Neill, T., Larson, N., Smith, J., Donia, M., Deng, C., Rosehart, W., & Brennan, R. (2019). Introducing a scalable peer feedback system for learning teams. Assessment & Evaluation in Higher Education, 44(6), 848–862. https://doi.org/10.1080/02602938.2018.1526256

[16] Bolick, M.A., Otterbeck, S., Headley, M., Taylor, E., Kaye, N., and Benson, L. (accepted) From Familiarity to Proficiency: Using an Updated Student Assessment of Learning Gains Survey to Guide Course Design in Engineering Statics. Paper presented at *2026 ASEE Annual Conference & Exposition*, Charlotte, NC.

References

Bandura, A. (2006). Guide for constructing self-efficacy scales. In: *Self-efficacy beliefs of adolescents*. Information Age Publishing; pp. 307–337.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84, 191-215.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice Hall.

Brown, S. & Burnham, J. (2012). Engineering Student's Mathematics Self-Efficacy Development in a Freshmen Engineering Mathematics Course. *International Journal of Engineering Education*. 28. 113-129.

Felder, R. M. & Brent, R. (2016). Teaching and Learning STEM: A Practical Guide (1st edition). Jossy-Bass.

Grigg, S., & L. Benson. (2015). Promoting Problem-solving Proficiency in First-year Engineering: PROCESS Assessment. Proceedings of the ASEE 2015 Annual Conference, Seattle, WA.

Hmelo-Silver (2004) "Problem-based Learning: What and How Do Students Learn?" *Educational Psychology Review*, **16**(3).

Husman, J., & Lens, W. (1999). The role of the future in student motivation. *Educational Psychologist, 34*(2), 113–125. https://doi.org/10.1207/s15326985ep3402

Jonassen, D.H. Toward a design theory of problem solving. ETR&D 48, 63–85 (2000). https://doi.org/10.1007/BF02300500

Jonassen & Hung (2008) "All problems are not Equal: Implications for Problem-Based Learning" *The Interdisciplinary Journal of Problem-based Learning* **2**(2).

[redacted] (20XX). [redacted]

Lord, S., Berger, E., Kellam, N., Ingram, E., Riley, D., Rover, D., Salzman, N., & Sweeney, J. (2017). Talking about a Revolution: Overview of NSF RED Projects. Paper presented at the ASEE Annual Conference and exposition, Columbus, OH.

Miller, R. B., & Brickman, S. J. (2004). A Model of Future-Oriented Motivation. Educational Psychology Review. 16(1), 9–33. https://doi.org/10.1023/B:EDPR.0000012343.96370.39

Min, T., Zhang, G., Long, R. A., Anderson, T. J., & Ohland, M. W. (2011). Nonparametric Survival Analysis of the Loss Rate of Undergraduate Engineering Students. Journal of Engineering Education, 100(2), 349–373.

O'Neill, T., Larson, N., Smith, J., Donia, M., Deng, C., Rosehart, W., & Brennan, R. (2019). Introducing a scalable peer feedback system for learning teams. Assessment & Evaluation in Higher Education, 44(6), 848–862. https://doi.org/10.1080/02602938.2018.1526256

Steif, P.S. and Dantzler, J.A. (2005), A Statics Concept Inventory: Development and Psychometric Analysis. Journal of Engineering Education, 94: 363-371. ttps://doi.org/10.1002/j.2168-9830.2005.tb00864.x

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