Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46898

The Real Problem of Problem Abstraction: Examining Performance and Self-Efficacy in a Civil Engineering Classroom

Evan Taylor, Clemson University

Evan Taylor is a Ph.D. candidate in the Department of Mechanical Engineering at Clemson University. His research through the VIPR-GS focuses on model-based systems engineering of ground vehicles. As a senior member of the CEDAR design group, he actively mentors and collaborates with fellow researchers. He plans to propose his dissertation on model fidelity evaluation and model selection in May 2025. He also develops his skills as an educator and community leader through education research and service in Graduate Student Government.

Dr. Lisa Benson, Clemson University

Lisa Benson is a Professor of Engineering and Science Education at Clemson University. Her research focuses on the interactions between student motivation and their learning experiences. Her projects include studies of student perceptions, beliefs and attitudes towards becoming engineers and scientists, and their development of problem-solving skills, self-regulated learning practices, and epistemic beliefs. Other projects in the Benson group involve students' navigational capital, and researchers' schema development through the peer review process. Dr. Benson is an American Society for Engineering Education (ASEE) Fellow, and a member of the European Society for Engineering Education (SEFI), American Educational Research Association (AERA) and Tau Beta Pi. She earned a B.S. in Bioengineering (1978) from the University of Vermont, and M.S. (1986) and Ph.D. (2002) in Bioengineering from Clemson University.

Dr. Nigel Berkeley Kaye, Clemson University

Nigel Kaye is a Professor in the Glenn Department of Civil Engineering at Clemson University. His primary research interests are in the fluid mechanics of natural hazards and in exploring ways to teach mechanics that improve student self-efficacy.

Makayla Headley, Clemson University

Makayla Headley is a doctoral student in the Department of Engineering and Science Education at Clemson University and an NSF Bridge to Doctorate Fellow. In addition to her Ph.D. studies, she is pursuing a Master of Science in Computer Science with a concentration in Software Engineering. She earned a B.S. in Chemical Engineering from the University of Maryland, Baltimore County (UMBC). Her dissertation research centers on engaging engineering students in the accreditation process, with the goal of aligning accreditation practices with students' career readiness. Through this work, she aims to Elevate STEM Students' Outlooks (ESSO).

The Real Problem of Problem Abstraction: Examining Performance and Self-Efficacy in a Civil Engineering Classroom

Abstract

One of the most fundamental skills in the domain of civil engineering is the ability to define a problem and draw a free-body diagram to represent it. These techniques involve abstraction, transforming a complex system from reality into a solvable and comprehensible set of forces and moments. This connection allows students to translate theoretical knowledge into practical application. As a result, fostering this abstract thinking is crucial in developing future engineers capable of identifying, formulating, and solving complex engineering problems, which is an ABET student outcome criterion. However, problems posed in current engineering courses do not always require students to perform these abstraction steps on their own. A well-structured, pre-abstracted problem reduces the cognitive load required to solve it and allows space for students to build other content knowledge, but it can limit students' ability to develop essential abstract thinking skills.

This paper explores students' self-efficacy for completing problem abstraction tasks and their overall performance in a sophomore-level engineering statics course that engages students in solving real-world, ill-defined statics problems. We pose the research question, "To what extent does problem abstractness correlate to students' self-reported perceptions of the problem, self-reported self-efficacy for solving the problem, and student performance in a statics course?" Findings from our quantitative data collection and analysis indicate that student Problem Solving Self Efficacy is strongly correlated with the level of problem abstraction and structuredness. As the problems are rated more real and less abstracted, the more groups identified with lower confidence and other negative emotions about their problem-solving skills. As a result, there was a drop in estimated problem score in more realistic problems. However, this did not translate into lower performance of the group on that problem, possibly due to the team-based nature of the course.

1 Introduction

"For the things we have to learn before we can do them, we learn by doing them" [1]. Engineering education program accreditation standards have increasingly emphasized the need for evidence that students have developed real-world problem-solving skills. For example, ABET student outcome 1 is the ability to "identify, formulate, and solve complex engineering problems" [2]. In response, engineering educators have engaged in Problem Based Learning (PBL), which has been shown to improve student motivation, knowledge retention, and problem-solving skills [3]. However, there are indications that the problems generated for the classroom do not mirror the ill-structured, complex, and multi-disciplinary problems encountered in the workforce [4]. Problems in the classroom, in contrast, typically have a rigid solution structure to demonstrate a specific concept. This gap between textbook and workplace problems may diminish the effectiveness of PBL interventions. In particular, we identify problem structure and abstraction as major influences on the problem solving capabilities of students [5].

In this study, we redesigned a sophomore-level engineering statics course that primarily relies on real-world, non-abstracted problems. The curriculum also emphasizes teamwork to help students engage with and solve problems of increasing complexity. Problems were written by the course instructor based on real-world contexts from the surrounding geographic area and from contexts and questions proposed by students in another mechanics course. We examined how varying levels of abstraction, as determined by the course instructor and students' self-reported perceptions of the problems, influenced student performance and self-reported problem-solving self-efficacy (PSSE). PSSE was measured through a survey developed based on a problem-solving rubric that assesses various steps in the problem abstraction and solving process, for example, problem statement and visual representation. The PSSE survey was completed by students in teams for each problem set. In parallel, the authors rated the level of difficulty of the problems based on a flipped variant of the same problem-solving rubric.

2 Literature Review

2.1 Problem Based Learning

Problem-Based Learning (PBL) is an increasingly utilized and invaluable tool for engineering education. First implemented by Barrows and Tamblyn in response to the limitations of traditional medical education—which often emphasized rote memorization over critical thinking and problem-solving skills—PBL has demonstrated significant benefits. Their initial study showed that students engaged in PBL exhibited greater skills and motivation than those in the control group [6].

PBL immerses students in real-world, short-term problems within collaborative and multidisciplinary environments. This active learning approach closely mirrors real-world scenarios and fosters skills that translate more effectively to the workplace. While not all studies have found that PBL leads to better content knowledge acquisition, the literature consistently highlights improved performance in the *application* of knowledge among PBL students. For example, Yadav et al. reported that electrical engineering students performed drastically better under PBL instruction, with enhanced learning transfer to new situations [7]. Furthermore, a meta-analysis of PBL outcomes revealed significant effects of PBL on the development of students' knowledge and skills [8]. Foundational research on the effects of expertise on problem solving skill development demonstrated such as adaptability and flexible knowledge [9], and the development of students' transferable skills and learning outcomes in PBL environments [10]. In addition to these benefits, PBL has been identified as an environment that facilitates metacognitive skills [8]. Metacognition, which in this context refers to the student's ability to evaluate their own thinking, is a crucial component of the problem-solving process [11].

2.2 Problem Solving Self Efficacy

Research has demonstrated that problem-solving ability is related to problem-solving self-efficacy [12]. For example, Dunlap observes that students are less likely to even engage in problem-based learning if they do not have the self-efficacy for doing so, and that as students gain experience in solving authentic, real-world problems, their confidence in engaging in those types of problems in the future increases [12]. This aligns with educational theory, which posits that one way to build students' self-efficacy is through mastery experiences [13]. In engineering contexts, where students are often faced with challenging design tasks, successful experiences are important in developing self-efficacy, which in turn fosters resilience and motivation. As a result, problem-based learning provides frequent, lower stake opportunities for reflection and confidence building. However, it must be noted that other factors contribute to self-efficacy, such as verbal feedback, prior experiences, gender, or physiological state [14]. Building self-efficacy may also translate into more proficient problem solving. Liu et al. showed that students with high self-efficacy were more aware of what learning tools were needed to solve a problem [15].

2.3 Theories of Problem Solving and Problem Structure

Problem based learning is effective in building the confidence and abilities of students to apply to the real world. However, the structure of the problems has an influence on the effectiveness of this practice. Commonly found problems in engineering textbooks usually consist of well-structured problems, with the focus being on finding a singular correct solution using a canonical solution pathway [5]. While a well-structured problem serves well to introduce and reinforce concepts, ill-structured problems are more closely associated with higher order thinking and professional skills.

In addition to problem type, there is a consideration of the problem-solving processes involved for the student. If the purpose of a problem is to evoke a set of problem-solving skills, then there is an inherent link between the structure of the problem and the cognitive processes of the student. Cognitive processes, as a field of study, have been divided amongst two main types of processes, similarity or rules based. Hahn and Chater described these two forms of cognition as opposing extremes on a two-dimensional spectrum of representation matching and abstraction [16]. Since representation and abstraction of a problem is a controllable aspect of course design, this may be a valuable avenue of research. For example, Johnson et al. found that using an abstract representation before a contextualized representation significantly increased the learning transfer of the students in the class [17]. Prior research has also decomposed the practice of problem solving into steps. The PROCESS rubric, developed by Grigg and Benson [18], has been used as a general guideline for the typical steps between problem presentation and solution communication. Figure 1 depicts this PROCESS methodology.

The first three steps of this are Problem Definition, Represent the Problem, and Organize the Information. These are clustered as conceptualization activities necessary to turn the problem into a calculable form. This construct mirrors that laid out by Jonassen, which describes two primary components of problem solving: the development of an internal representation of the problem, and the transformation or manipulation of the problem space [15]. This development of a coherent and solvable representation of the problem is a crucial skill in the domain of civil engineering and is crucial to student success. As a result, a problem's structure may influence how much of this work is left to the student, which may have significant influence on the self-efficacy, skill development, and academic performance of students

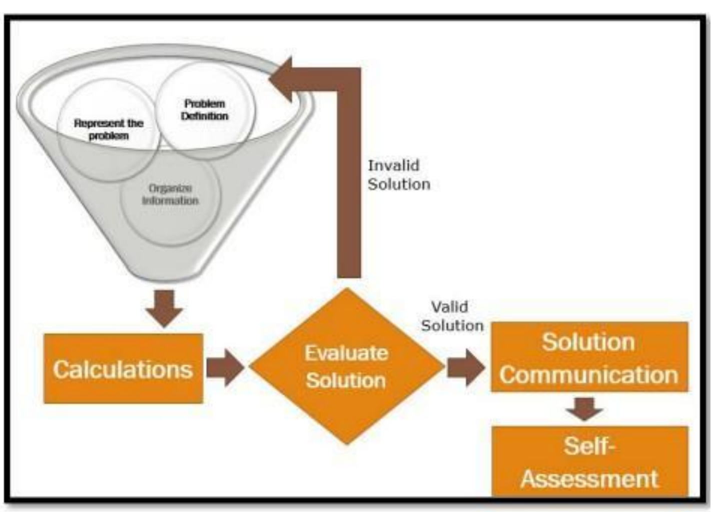

Figure 1: Problem Solving PROCESS, from Grigg and Benson [18]

3 Methodology and Class Structure

The focus of this study is a sophomore level civil engineering statics course, that utilizes teams in Problem Based Learning. There are three categories of data collection in this study:

1. Problem Solving Self Efficacy
2. Ratings of Problem Structuredness and Level of Abstraction
3. Student Performance Outcomes

An important point of distinction is the team-based nature of the course. Most of the assignments were completed in teams. As a result, many of the conclusions that can be reached from this data set speak to how students working in *teams* are affected by problem structuredness and abstraction. Future data analyses will include individual as well as team-based effects.

3.1 Problem Solving Self Efficacy

Students submitted their solutions with a homework cover sheet that included a Problem-Solving Self Efficacy (PSSE) assessment. These homework sets were completed in teams, with one submission for the entire team. As a result, problem sets 1.1 and 2.1 were removed from the data set due to duplicate and conflicting submissions from some teams.

The cover sheet consists of five items related to PSSE, a field for estimating their performance on each problem, and a free response field for other comments. The questions are provided in Figure 2.

Data Label		Q1	Q2	Q3	Q4
Estimated	Estimate your score on each problem	/20	/20	/20	/20
	Rate your team's experience completing this problem below on a scale of 0 (not at all) to 10 (very much)				
PSSE 1	Our group had the knowledge and mathematical skills needed to solve this problem				
PSSE 2	We felt hurried or rushed when completing the problem				
PSSE 3	We could successfully complete a similar problem to this in the future				
PSSE 4	We put in a lot of effort to complete this problem				
PSSE 5	We felt insecure, discouraged, irritated or stressed while solving this problem				
	Add any other comments about this assignment in the box below.				

Figure 2: Cover sheet questions that prompt students to self-assess their Problem-Solving Self-Efficacy (PSSE) with additional data labels

In addition to recording the numerical values of this cover sheet, the absence of this data was also recorded. Missing entries on the PSSE coversheet were coded as "BLANK", and values that fell outside the rating scheme, such as a 20/10 on the PSSE sheet were recorded as "***". As a result, these missing or aberrant values were removed from the correlation analysis performed in Section 4 but analyzed further for other trends.

3.2 Problem Abstraction and Structure

The PROCESS rubric was used in the class to grade the responses to the homework problem. Each step of the problem, from problem definition to self-assessment needs to be presented for students to receive full credit for the problem. However, the course comprises many real world problems, which may be less abstract than other problems in the course. As a result, this study aims to rate the information given in the problem to the student, particularly in relation to the

"PRO" elements of the PROCESS rubric. These rubrics are shown in Figure 3.

	Problem Solving PROCESS		
(7 iterative stages)	Missing	Vague	Complete
Problem Definition • Summarize the problem • Identify desired value & units • Identify constraint(s) • Communicate assumption(s)	0	1	2
Represent the Problem • Sketch a representation • Relate variables	0	1	2
Organize Information • Identify known values • Identify equations • Identify conversion factors	0	1	2
Calculations • Manipulate equations • Document math • Convert to desired units	0	1	2
Evaluate Solution • Check accuracy • Check units	0	3	5
Solution Communication • Indicate final answer • Check reasonableness • Justify solution	0	3	5
Self-Assessment • Rate your performance above	0	1	2

(a) PROCESS rubric used to provide formative feedback to students on homework problems.

Problem Category	**Problem Structure Rating**		
	Missing: 0	Low: 1	High: 2
Problem Definition	Ill-defined problem, diverging responses to problem.	Problem is partially or implicitly defined	Problem is clearly and explicitly defined
Assumptions	Students may reasonably assume differently	Not all the assumptions needed are explicitly given	All necessary assumptions are explicitly
Abstracted Representation	Real world representation of system	Minimal simplifications are provided; real-world elements dominate the representation.	Fully simplified representation, (e.g. point masses, two force members), to enable problem solving
Knowns and Unknowns	Variables must be measured or assumed.	Some knowns or unknowns are listed, but the information is incomplete or unclear.	All knowns and unknowns are explicitly stated in the problem
Solution Structure and Equations	Students may use different methods of solution.	The solution structure needed is implicitly or partially given.	The necessary solution structure and equations are explicitly indicated

(b) Flipped "PRO" portion of the PROCESS rubric used by the research team to rate problems in terms of level of abstraction and definition.

Figure 3: The PROCESS Rubric and its Flipped Variant for Rating Problem Abstraction

The PRO portion of the rubric provides a method to rate the various aspects of problem abstraction. In this construct, an ill-structured, "greenfield" real world problem would correspond to all zeros on this chart. This problem requires full abstraction for the student to solve, as there is no given information in the problem. For example, a problem of this type might ask, "What type of cable is needed to support a traffic light?" This problem would receive zeros on all categories, as justified in the table below.

Table 1: Rating scale for a real-world, ill-structured problem assigned in the course.

Problem Category	**Rating**	**Justification**
Problem Definition	0	The problem is not clearly defined. Students may arrive at different conclusions as to what the required solution of the problem is.
Assumptions	0	No assumptions are given. e.g. Static Equilibrium.
Abstracted Representation	0	Only given a real-world picture of a traffic light.
Knowns and Unknowns	0	Measurements or assumptions have to be made to proceed.
Solution Structure and Equations	0	No indication of how the problem should or can be solved.

In contrast, a problem with all 2's would be equivalent to a free body diagram of the scenario with all necessary elements for calculation explicitly listed. In this case, all that would be left to do is the calculation, evaluation, solution communication and self-reflection, or the “CESS pool” of the PROCESS rubric.

The ratings of the homework problems in the course were conducted by two members of the research team, the course instructor and graduate research assistant with disciplinary expertise in mechanical engineering. For the correlation data in Section 4, the cumulative score in the 5 abstraction categories were summed and averaged across the two raters. While agreement between the raters was high for the Problem Definition, Abstracted Representation, and Knowns and Unknowns, the other two categories did not have strong agreement. The primary difficulty with rating problem abstraction is the interrelationship between many of the categories in the rating scale. Problem abstraction cannot be neatly orthogonalized into independent aspects. Assumptions are needed to draw an abstract representation, problem definitions that indicate knowns and unknowns are necessary, etc. As a result, the sum of these aspects could be used to represent overall problem abstraction through the individual categories. Future work will adjust and validate this rating tool with a larger team of raters and assessment of inter-rater reliability (Cohen’s kappa).

3.3 Problem Solving Performance

Course graders assessed the homework problems using the PROCESS rubric found in Figure 3a. Each problem was individually graded, which enabled analysis of student performance on each homework problem. All problems in the course were graded out of 20 points and were submitted in sets of 4 problems by teams (one submission per team). Another source of student performance were students’ final course grades, which were used to assess the outcome of students engaging in self-reflection. Because the self-reflection entailed the PSSE items on the cover sheet that were completed in teams, a final course grade for each team was calculated by averaging the final grades for individual students within a team. While this was not the main research question, engaging in self-reflection can affect self-efficacy and therefore contributed to our understanding of the results of this study.

3.4 Analysis Methods

The primary method used to determine the relationship between PSSE, abstraction level, and performance is Pearson correlation coefficient. This coefficient is a dimensionless measure of the covariance between two variables, normalized between -1 and 1 [19]. These extremes represent exact linear relationships between the variables. As a result, interpretation of this coefficient can lead to some inferences about the relationship between the data collected. In addition, a t-test for statistical significance can be used to indicate whether the correlation coefficient is significantly different than zero, which indicates that there is no clear linear relationship between the variables [19]. Another method of analysis that was conducted is a paired *t*-test to analyze if the difference in means between two correlated measurements is significant [20].

4 Results and Discussion

Pearson correlation coefficients were calculated to analyze the relationship between the PSSE cover sheet data, the teams’ performance on the problem, and the average overall abstraction rating from the raters. A table summarizing the correlation coefficients for these data sets is shown in Figure 4. PSSE 1 through PSSE 5 correspond to the cover sheet questions found in Figure 2, using a shortened phrase to summarize the gist of each item. In Figure 4, correlation coefficients are bolded to indicate statistically significant correlations among the sample of 67 homework problems. As problem abstraction and structuredness ratings increased, we observed a decrease in teams' perceptions of having the requisite skills to solve the problem, confidence about being able to solve the problem, and confidence about solving a similar problem in the future, and an increase in negative emotions (insecure, discouraged, distressed, or stressed). These results are explained in more detail below.

	PSSE 1	PSSE 2	PSSE 3	PSSE 4	PSSE 5	Score Estimate	Actual Score	Abstraction Level
PSSE 1: Requisite knowledge	1.00							
PSSE 2: Feeling rushed	**-0.37**	1.00						
PSSE 3: Complete a similar problem	**0.83**	**-0.48**	1.00					
PSSE 4: Effort	**-0.67**	0.22	**-0.57**	1.00				
PSSE 5: Negative emotions	**-0.76**	**0.31**	**-0.71**	**0.69**	1.00			
Score Estimate	**0.76**	**-0.44**	**0.66**	**-0.52**	**-0.62**	1.00		
Actual Score	0.20	**-0.31**	**0.38**	-0.03	-0.14	0.18	1.00	
Abstraction Level	**-0.58**	0.13	**-0.53**	**0.59**	**0.50**	**-0.41**	-0.16	1.0

Figure 4: Pearson correlation coefficients for comparisons between student perceptions of their Problem Solving Self-Efficacy (PSSE), score estimates, actual score and level of abstraction/structuredness for the 67 homework problems assigned in this course.

4.1 PSSE and Performance

All five of the PSSE questions have a statistically significant Pearson correlation coefficient in predicting the estimated students' homework grade ($p < .05$). However, not all of the PSSE questions have a strong correlation to the score that the teams received on that problem. It was found that teams that identified more with the statement "We could successfully complete a similar problem to this in the future" performed better on homework problems, and teams that felt rushed or hurried (PSSE 2) performed worse on homework problems. Confidence in problem solving skills has been shown to be related to better student outcomes in literature [21]. In addition, the schedule of the course was affected by Hurricane Helene, which caused widespread internet and power outages. As a result, the course was effectively compressed by two weeks. This effect can be measured by performing a paired *t*-test on PSSE 2 of the cover sheets before and after the hurricane.

Table 2: Effect of a natural disaster occurring in the region (Hurricane Helene) on students' perceptions of feeling rushed (PSSE 2) when completing homework problems.

Category	Before Hurricane Helene	After Hurricane Helene
Mean	1.651	2.019
Standard Deviation	.666	.724
Number of Problems	23	44
p-value	**0.047**	

While not all of the PSSE questions had statistically significant correlation with homework outcomes, completion of the cover sheet we found to strongly correlate with students' final course grade as shown in Figure 5. The PSSE used in this study constituted a cover sheet that students submitted with their completed homework; completion of which constituted a minor portion of the homework grade. Even accounting for this penalty, PSSE completion is an indicator of student performance in the course. Figure 5 shows the relationship between teams' final grade and the number of missing fields on their PSSE assessment sheets.

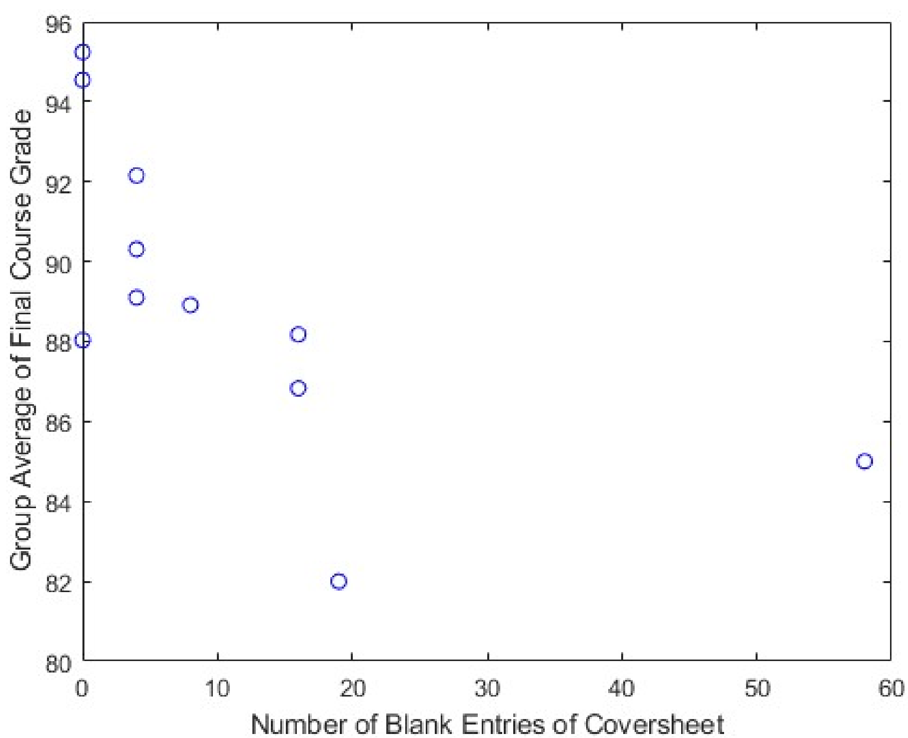

Figure 5: Interactions between teams' completion of PSSE self-assessment (as indicated by the number of blank entries on the cover sheet) and teams' final course grades.

Correlations between the number of blank entries on the PSSE cover sheet questions and the average final course grades for the 11 teams of students (n=11) was examined by calculating the Pearson coefficient (-.619) and p-value (.042), which indicate a significant negative linear correlation. It has been shown in literature that engaging in self reflection, and in general, metacognition, can improve student performance [10], which may be the underlying mechanism of the negative correlation between incomplete self-assessments and student performance in the course. However, teams that perform well within a class in terms of grades may be more meticulous in general, including completing the PSSE cover sheet self-assessments. Future work should provide a methodology to separate these effects.

4.2 Abstraction and PSSE

The level of problem abstraction had a statistically significant effect on PSSE in four out of the five questions asked. In addition, the PSSE question that did not have a statistically significant correlation with abstraction level was PSSE 2, which relates to the team being hurried or rushed. While real-world problems may take more time to solve, it would be expected that other factors have a much more significant effect on the student's feelings of being rushed. In general, the strong correlations between abstraction level mean that students find these problems to be more challenging. An interpretation of this category of results is found in Table 3.

Table 3: Interpretation of Abstraction Level Correlations

PSSE Question	Correlation with Abstraction Level	Interpretation
PSSE 1: **Requisite knowledge**	-.58	As a problem becomes more real and less abstract, the less that groups feel like they have the knowledge required to solve the problem
PSSE 3: **Complete a similar problem**	-.53	As a problem becomes more real, the less that groups feel like they could solve a similar problem in the future.
PSSE 4: **Effort**	.59	As a problem becomes less real and more abstract, the more work students had to put in to solve the problem.
PSSE 5: **Negative emotions**	.50	As the problem becomes less abstract and more real, the more discouraged, irritated, or stressed the students felt.

It can be noted that PSSE 4 deviates from the expectation that real world problems would involve more work (e.g., problem abstraction, translating real world components into a free body diagram) because the context is farther removed from a numeric solution. However, the data indicates that student felt that the real world problems required less work. This conflict can be explained by looking at the types of problems included in the dataset. A common type of "real world" problem within the dataset is a conceptual check in which the students were asked to, in free response, analyze real world examples of statics systems in conceptual terms. As a result, students may have put less effort into solving these homework problems. In future work, a coding scheme should be implemented to sort and control for the problem type.

4.3 Abstraction and Performance

Abstraction level has a statistically significant negative correlation on the estimated performance on the homework problems in the set. This is unsurprising, as the students identified more strongly with negative self-efficacy standards for real-world problems, as detailed in Section 4.2. However, there is not a statistically significant correlation between the actual score of the students on these problems and the abstraction level. While abstraction level has a significant correlation to how students perceive themselves and the problem, this effect does not translate into a drastically different performance. This result may be due to the team-based nature of PBL implemented in this course. Since the teams work on and submit the problems as a team, team members must perform abstraction and conceptualization activities together. As a result, it may be done more correctly than if these problems were solved individually. Team based homework allows for students to perform these abstraction activities in low-stakes environments, which may increase development of problem-solving skills.

5 Conclusion

This study investigates the effect of problem abstraction on students' performance, self-reported perceptions about the problems, and problem-solving self-efficacy (PSSE) in a sophomore-level engineering statics course. Results indicate that decreasing levels of abstraction (real-world problems) produced decreased self-efficacy ratings. However, this did not translate into a statistically significant reduction in homework assignment performance. Although confidence was lowered in the presence of ill-defined, real-world problems, student groups could perform at a level suggesting collaboration may mitigate some adverse effects on self-efficacy.

Furthermore, the engagement of students in self-reflection as indicated by the PSSE cover sheets is a key predictor of academic success in the course. Cohorts that regularly fulfilled the self-assessment components achieved higher final grades, suggesting that engaged and systematic reflection can enhance metacognitive abilities. By encouraging metacognitive activities, engineering educators may establish a feedback mechanism that strengthens problem-solving capabilities.

The findings depict the complex interactions between problem design, student self-reflection, and subsequent student performance. While non-abstracted problems are crucial in preparing students for professional practice, instructors need to consider interventions that will strengthen students' confidence in facing these challenges. Future research will focus on refining the abstraction rating tool (based on the “PRO” portion of the PROCESS rubric) for better inter-rater reliability and analyzing individually answered test or quiz items to remove the effect of group work.

References

[1] Aristotle, W. Ross, J. Ackrill, and J. Urmson. *The Nicomachean Ethics*. Page 3. Oxford University Press, 1998.

[2] ABET. Criteria for accrediting engineering programs 2024-2025, Dec 2023.

[3] A. M. Clyne and K. L. Billiar. Problem-based learning in biomechanics: advantages, challenges, and implementation strategies. *Journal of Biomechanical Engineering*, 138, 2016. doi: 10.1115/1.4033671

[4] D. H. Jonassen, J. Strobel, and C. B. Lee. Everyday problem solving in engineering: lessons for engineering educators. *Journal of Engineering Education*, 95:139–151, 2006. doi: 10.1002/j.2168-9830.2006.tb00885.x

[5] David H. Jonassen. Toward a design theory of problem solving. *Educational Technology Research and Development*, 48(4):63–85, Dec 2000. doi: 10.1007/bf02300500

[6] H. S. Barrows and R. M. Tamblyn. An evaluation of problem-based learning in a small groups utilizing

a simulated patient. *Journal of Medical Education*, 51(1):52–54, 1976.

[7] A. Yadav, D. Subedi, M. Lundeberg, and C. F. Bunting. Problem-based learning: influence on students' learning in an electrical engineering course. *Journal of Engineering Education*, 100:253–280, 2011. doi: 10.1002/j.2168-9830.2011.tb00013.x

[8] Dochy, F., M. Segers, P. Van den Bossche, and D. Gijbels. 2003. "Effects of Problem-Based Learning: A Meta-Analysis." *Learning and Instruction* 13 (5): 533–568. doi: 10.1016/S0959-4752(02)00025-7

[9] Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (vol. 1, pp. 7-76). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

[10] Chaparro-Peláez, J., S. Iglesias-Pradas, F. J. Pascual-Miguel, and Á Hernández-García. 2013. "Factors Affecting Perceived Learning of Engineering Students in Problem-Based Learning Supported by Business Simulation." *Interactive Learning Environments* 21 (3): 244–262. doi: 10.1080/10494820.2011.554181

[11] Veenman, M.V.J., Van Hout-Wolters, B.H.A.M. & Afflerbach, P. Metacognition and learning: conceptual and methodological considerations. *Metacognition Learning* **1**, 3–14 (2006). https://doi.org/10.1007/s11409-006-6893-0

[12] Dunlap, J.C. Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *ETR&D* **53**, 65–83 (2005). https://doi.org/10.1007/BF02504858

[13] A. Bandura. Self-efficacy. *Encyclopedia of Health and Behavior*, 2004. doi: 10.4135/9781412952576.n182.

[14] M. Hutchison, D. Follman, M. Sumpter, and G. M. Bodner. Factors influencing the self-efficacy beliefs of first-year engineering students. *Journal of Engineering Education*, 95:39–47, 2006. doi: 10.1002/j.2168-9830.2006.tb00876.x

[15] Min Liu, Ying Cai, Songhee Han, and Peixia Shao. Understanding middle school students' self-efficacy and performance in a technology-enriched problem-based learning program: A learning analytics approach. *Journal of Educational Technology Systems*, 2023. doi: 10.1177/00472395231174034.

[16] Ulrike Hahn and Nick Chater. Similarity and rules: distinct? exhaustive? empirically distinguishable? *Cognition*, 65(2):197–230, 1998. ISSN 0010-0277. doi: https://doi.org/10.1016/S0010-0277(97)00044-9. URL https://www.sciencedirect.com/science/article/pii/S0010027797000449.

[17] Amy M. Johnson, Jana Reisslein, and Martin Reisslein. Representation sequencing in computer-based engineering education. *Computers Education*, 72:249–261, 2014. ISSN 0360-1315. doi: https://doi.org/10.1016/j.compedu.2013.11.010. URL https://www.sciencedirect.com/science/article/pii/S0360131513003217.

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

[19] Schober, Patrick MD, PhD, MMedStat; Boer, Christa PhD, MSc; Schwarte, Lothar A. MD, PhD, MBA. Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia & Analgesia 126(5):p 1763-1768, May 2018. | DOI: 10.1213/ANE.0000000000002864

[20] Xu, M., Fralick, D., Zheng, J. Z., Wang, B., Tu, X. M., & Feng, C. (2017). The Differences and Similarities Between Two-Sample *T*-Test and Paired *T*-Test. *Shanghai archives of psychiatry*, *29*(3), 184–188. https://doi.org/10.11919/j.issn.1002-0829.217070

[21] Astutiani, Risma, et al. "Problem solving ability considered by self confidence in digital media assisted online learning". Kreano, Jurnal Matematika Kreatif-Inovatif, vol. 12, no. 2, 2021, p. 323-334. https://doi.org/10.15294/kreano.v12i2.30828