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BOARD # 189: WIP: Using the Statics Concept Inventory to Assess Hands-On Learning in Statics

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WIP: Using the Statics Concept Inventory to Assess Hands-On Learning in Statics

Abstract

This work-in-progress paper examines the use of didactic materials and hands-on activities in statics to reduce student errors and enhance concept application. By integrating problem-solving studio sessions with the Statics Concept Inventory, the goal is to transform traditional instruction into engaging, studio-like environments aligned with entrepreneurially minded learning (EML).

Assessment involves pre- and post-tests comparing control and experimental groups, alternating the use of PASCO Statics System sets. Post-tests measure conceptual understanding, while surveys capture student perceptions. This rotational design enables direct comparison, allowing statistical analysis of the impact of hands-on activities on learning.

Introduction

This work-in-progress presents findings from a pilot implementation aimed at introducing fundamental concepts in statics courses for aerospace, civil, and mechanical engineering students. The approach involved organizing students into small teams to follow detailed step-by-step handouts for replicating a lab using a statics set.

Statics courses often present significant challenges for students due to the abstract nature of the fundamental concepts involved. Prior research has identified difficulties in conceptualizing forces, equilibrium, and moments as common obstacles for engineering students [1]. Traditional instructional methods, such as lectures and textbook problems, may not always be sufficient to facilitate deep comprehension, necessitating innovative pedagogical strategies that promote interactive and experiential learning [2].

This study investigates the integration of hands-on learning tools and the principles of entrepreneurially minded learning (EML) [3] to create studio-like environments that foster active engagement and deeper comprehension. Previous studies have demonstrated that hands-on experiments and interactive problem-solving exercises enhance student motivation and performance in engineering mechanics: statics [4]. By incorporating problem-solving studio sessions [5, 6] and structured mini-labs using PASCO scientific instruments [7], this initiative aims to improve student learning outcomes while cultivating an entrepreneurial mindset that encourages curiosity, connections, and value creation [3].

Entrepreneurially Minded Learning (EML)

EML offers a compelling framework for addressing these challenges. Developed through the KEEN (Kern Entrepreneurial Engineering Network) [3] initiative, EML focuses on fostering the "3Cs" in students: Curiosity, Connections, and Creating Value. This approach encourages students to ask critical questions, draw meaningful connections between concepts, and understand the broader implications of their learning in solving real-world problems [8].

In this study, EML principles are integrated with hands-on tools to create studio-like environments that promote active engagement and deeper comprehension in statics courses. By incorporating problem-solving studio [5] sessions and structured mini-labs using PASCO scientific instruments, the initiative aims to improve student learning outcomes while developing their entrepreneurial mindset.

Statics Concept Inventory

The Statics Concept Inventory (SCI) is a specialized assessment tool designed to evaluate students' understanding and application of fundamental concepts in engineering statics [1-3, 9]. Developed by Steif and Dantzler [1], the SCI employs multiple-choice questions that probe students' abilities to utilize these concepts effectively in problem-solving scenarios and identify common misconceptions in the subject matter.

The SCI was developed by identifying core concepts and typical student errors through prior studies. This effort led to the creation of an assessment tool aimed at quantifying conceptual understanding in statics, an essential area of study for engineering students. The inventory focuses not only on information recall but also on the practical application of statics principles in solving engineering problems.

The SCI has undergone rigorous validation to ensure its effectiveness [2, 6, 9-11]. Content validity checks involving focus groups and faculty surveys confirmed the relevance of its items. Concurrent validity was established by correlating SCI scores with course grades in engineering statics, highlighting its accuracy in assessing conceptual understanding. Furthermore, the SCI has demonstrated high reliability across diverse student populations, affirming its suitability for broad use in engineering education.

Recent studies have extended the use of the SCI to analyze differences in conceptual understanding between students and practicing engineers, shedding light on how statics knowledge develops over time [11]. Additionally, research has demonstrated the reliability of concept inventories in assessing students' conceptual grasp beyond procedural problem-solving [6]. These findings reinforce the SCI's role not only as an assessment tool but also as a diagnostic instrument that helps educators identify misconceptions and refine instructional strategies [7].

Beyond measuring conceptual understanding, the SCI serves as a diagnostic tool for analyzing common student errors [1]. By evaluating student responses, instructors can identify recurring mistakes and adjust instruction to address these gaps. This process aligns with the theory of situated cognition, emphasizing that learning is influenced by the context in which students engage with statics concepts.

In this paper, three topics from SCI, namely vectors, rigid body equilibrium, and moment, were selected to develop pre- and post-questionaries. Appendix A provides information about these questions.

Methods

This project was implemented in a freshman and sophomore-level Statics course at our university. Students were organized into teams of three to four to facilitate a rotational experimental design. One team served as the experimental group, using didactic materials and PASCO instruments, while the other team completed tasks without these tools. For this pilot study, only selected concepts were tested.

Each student completed a pre-test questionnaire before the mini-lab session and a post-test questionnaire afterward, both consisting of the same three questions. This allowed for a direct comparison of student understanding before and after the mini-lab. Additionally, a short survey was administered at the end of the post-test to assess students' opinions on the experience.

Tools and Materials

PASCO Statics System: Used to provide hands-on exploration of forces, moments, and equilibrium [7].

Procedure

- *Pre-Test:* Administered before each mini-lab to evaluate baseline knowledge of vectors, moments, and equilibrium. See Appendix A.
- *Mini-Labs:* Three mini-labs were conducted over the semester. Students alternated roles, with one team using the statics sets while the other completed tasks without them. Each lab concluded with a topic-specific post-test. The mini-labs were modified versions of the setups from Experiments 2 to 5, as provided by [12].
- *Post-Test:* Administered immediately after each mini-lab, using the same questions as the pre-test to assess knowledge gains.

Data Collection and Analysis

During this pilot phase, the pre- and post-tests were administered. The data was not reported as it provided no significant information. This is likely due to the students having already been exposed to the material, rendering the assessments redundant. As a result, only qualitative feedback is considered in this paper. Student surveys were conducted to gather insights into their perceptions of the learning tools, focusing on how these tools influenced their comprehension of key concepts, engagement with the material, and overall learning experience. **Table 1** presents the students' responses on a Likert scale to specific questions regarding the complexity, engagement, and learning effectiveness of the mini-labs. Only the answers of students who completed the minilabs were reported in **Table 1**.

Based on the qualitative findings, modifications will be made to enhance the students' experience and learning outcomes in the upcoming spring semester. These adjustments will aim to address identified challenges and improve the implementation of the learning tools, ensuring a more effective integration into the curriculum.

Table 1. Student Feedback on the Complexity, Engagement, and Learning Effectiveness of Mini-Labs in Statics Courses

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Regarding the complexity of the minilabs.						
The instructions in the mini-labs were easy to understand.	2	12	8	0	0	**22**
I found the mini-labs activities to be engaging and enjoyable.	8	8	5	1	0	**22**
The equipment and materials used in the mini-labs were appropriate and easy to work with.	4	13	4	1	0	**22**
Regarding your understanding of the topics.						
The mini-labs helped me learn new concepts related to forces, moments (torque), and vectors.	4	10	7	1	0	**22**
The mini-labs reinforced my understanding of previously learned concepts about forces, (moments) torque, and vectors.	10	10	2	0	0	**22**
You recommend the use of these or similar mini-labs in Statics courses in the coming semesters	5	14	3	0	0	**22**

Table 2 presents the qualitative feedback provided by students to improve the mini-lab experience. Comments were grouped into key categories, including suggestions for improving setup instructions, positive feedback on the learning experience, logistical issues, and additional recommendations. Many students highlighted the need for clearer instructions, with suggestions such as including videos or step-by-step visuals to simplify the setup process. Positive feedback emphasized the mini-labs' effectiveness in visualizing and reinforcing class concepts. Logistical concerns, such as missing items and the classroom environment, were also noted. Additionally, students suggested offering similar mini-labs throughout the semester to enhance understanding of course topics and provide opportunities for extra credit.

Table 2. Student Comments and Suggestions for Improving the Mini-Lab Experience.

Category	Comment
Suggestions for Setup Instructions	- Including a video or step-by-step pictures for how to set up each part of the labs would be helpful, as figuring out the pieces and their usage was the hardest part. - Setting up the board was difficult, but once figured out, the lab was fun. The second lab was harder to understand than the first. - Instructions for the second lab were challenging regarding pulley movement to angles, but we realized the pivot point had to be kept in equilibrium and adjusted accordingly. - Instructions could be more in-depth, but the mini-lab was enjoyable after it worked.
Positive Feedback	- The mini labs helped me understand the concepts better by seeing forces in action and counteracting each other. - Pretty good lab and easy to follow. - Once I understood the objective, it visualized class concepts effectively
Logistical Issues	- Groups should organize and return all items after the lab. Missing items from prior groups made the lab unnecessarily confusing. - The heat in the room made it hard to enjoy, although some overlooked this issue
Additional Suggestions	- Offering mini-labs throughout the semester would help understand real-world applications of class topics and could include extra credit since they were out-of-class assignments.

Results and Analysis

The results from the student surveys highlighted several key themes regarding the mini-labs, pointing out both strengths and areas that could benefit from improvements.

In terms of the clarity of instructions, 63.6% of students felt that the instructions were easy to follow. However, 36.4% of students remained neutral, suggesting that there is potential for enhancing the clarity or adding more detail to the guidance provided. This indicates that some students may have found the instructions lacking in certain areas, and refinements could help address this gap.

When looking at engagement, it was noted that 72.7% of students found the activities engaging. Still, 22.7% were neutral, and 4.5% disagreed, signaling that not all students were fully immersed in the activities.

Regarding the materials and equipment used, 77.3% of students felt that they were appropriate for the mini-labs. However, 18.2% were neutral, and 4.5% disagreed, which points to potential issues with the usability of the materials. These concerns could be further explored to ensure that all equipment serves its intended purpose effectively.

In terms of topic understanding, the mini-labs were particularly successful in reinforcing previously learned concepts, with 90.9% of students expressing positive feedback. This shows that the mini-labs were effective in strengthening foundational knowledge. On the other hand, when it came to learning new concepts, 63.6% felt that the mini-labs helped in this area, while 31.8% were neutral.

Overall, the mini-labs were well-received, with 86.4% of students recommending their continued use in future courses. This indicates strong support for the ongoing integration of mini-labs in the curriculum, despite areas that could benefit from further refinement.

Key Trends:

The analysis uncovered a few clear patterns. The mini-labs were particularly effective in reinforcing understanding, as shown by the 90.9% positive feedback regarding prior knowledge. Additionally, there was overwhelming support for their continued use, with 86.4% of students recommending the mini-labs for future courses. The materials and equipment were generally considered suitable, with 77.3% of students expressing approval.

However, two key areas stood out for improvement. First, the clarity of instructions could be enhanced, as 36.4% of students felt neutral about the clarity provided. Second, the introduction of new concepts could be more effective, as 31.8% of students reported feeling neutral about how well new material was conveyed.

Recommendations:

1. *Improve Instructions:* Incorporate detailed, step-by-step guides, possibly with diagrams or videos to improve clarity.
2. *Enhance Engagement:* Use real-world examples or challenges to foster an entrepreneurial mindset by encouraging problem-solving, creativity, and innovation.
3. *Address Equipment Usability:* Gather more detailed feedback on any usability issues with materials and equipment to resolve specific concerns.
4. *Support Learning Gaps:* Offer additional resources or explanations to help students who struggled with new concepts, ensuring everyone is fully supported.

Qualitative Feedback

Engagement: Hands-on activities, particularly the use of PASCO sets and mini-labs, were highly engaging and instrumental in making abstract concepts more tangible for students.

Application: The real-world relevance of the mini-labs and experimental tasks resonated with students, highlighting their appreciation for how these activities helped them bridge the gap between theory and practice.

Challenges: While students initially faced challenges in applying theoretical knowledge to practical tasks, these difficulties gradually diminished as they gained more experience with the tools and concepts.

Conclusions and Future Work

This study shows the effectiveness of incorporating didactic materials and hands-on learning to deepen conceptual understanding in statics. The rotational design and the use of PASCO instruments were particularly successful in boosting student engagement and enhancing learning outcomes.

Future work will focus on the following:

1. Administer pre- and post-lab tests for each mini-lab and analyze the data to compare the results with those of the previously published literature on the Static Concept Inventory (SCI).
2. Incorporate real-world examples while still analyzing individual concepts to enhance engagement and foster the entrepreneurial mindset.
3. Expanding the study to include larger cohorts and a more diverse student population, if possible.
4. Refining the didactic materials to overcome challenges encountered during initial integration.
5. Evaluating the long-term retention of knowledge and skills acquired through these methods.
6. Investigating the impact of these techniques on advanced courses such as dynamics and the mechanics of materials.
7. Include peer evaluations to encourage constructive feedback, enhance accountability, and promote deeper engagement.
8. Integrating additional tools and technologies to further enhance the learning experience.

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Appendix A: Pre and post-Lab Questionnaire [13]:

The pre-lab questionnaire consisted of 15 multiple-choice questions assessing students' knowledge across three topics: vectors, rigid body equilibrium, and moment. These questions were selected from the AIChE Concept Warehouse [13], a question inventory website freely available to educators. The warehouse was developed through multiple NSF grants (DUE 1023099, 1225221, 1245482, 1821439, and 2135190). Each question in the warehouse has a unique identification code. The following questions from the warehouse were included in both the pre- and post-lab tests

Questions related to vectors assessed students about Vector Addition (question code Q6404), comparing forces (question code Q5738), comparing forces (question code Q5737), sum of magnitudes vs magnitude of resultant (question code Q5857) and minimizing the magnitude of a force (question code Q6402).

Questions related to rigid body equilibrium were related to pushing a filing cabinet (question code Q7184), 2D moment concepts (question code Q7177), rigid body equilibrium (question code Q6217), taught cable (question code Q6469), and 2D equilibrium conditions (question code Q6066).

Questions related to moments assessed students about moment from force on a rigid body (question code Q5483), moment about a point (question code Q4972), Moment from force on a rigid body (question code Q5482), Moment about a point (question code Q4973), and moment from force on a rigid body (question code Q5485)