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Is It Problem or Project-Based Instruction: Implementing PBI for the First Time in an Engineering Mechanics College Course

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Abstract: This mixed methods study investigated a college engineering professor's first-time implementation of project/problem-based instruction (PBI) within an engineering mechanics (EM) course and compared this implementation with a business-as-usual (BAU) EM course. Research questions concerned the degree to which the PBI course changed from a BAU model and the effectiveness of the PBI implementation on students' EM learning as measured by a Statics Concept Inventory as compared to BAU students. Findings showed the professor's original intentions and realizations of project-based instruction had to be adjusted to a problem-based instructional format to keep it in line with the EM course objectives (simply better suited as problem-based).

Keywords: project-based; problem-based; undergraduate engineering

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Citation: Daddysman, J.A.; Wilhelm, J.A.; Taghaddosi, F. Is It Problem or Project-Based Instruction: Implementing PBI for the First Time in an Engineering Mechanics College Course. *Educ. Sci.* **2023**, *13*, 175. https://doi.org/10.3390/educsci13020175

Academic Editor: Randall S. Davies

Received: 5 January 2023
Revised: 3 February 2023
Accepted: 5 February 2023
Published: 7 February 2023

1. Introduction

Like many of its related disciplines, engineering education is often structured around lecture-based courses that use traditional examinations and teacher-centered approaches. In the early 1990s, engineering professionals in North America noted that new engineers entering the workforce lacked skills essential to succeed in the profession, including communication and design skills [1]. Mills and Treagust [2] identify similar issues in engineering education, including lack of design experience in program graduates, lack of communication and team skills among graduates, and lack of teaching on holistic engineering that includes "social, environmental, economic, and legal issues" (p. 3). Due to these gaps in knowledge and experience, engineering program guidelines began to shift focus from lists of topics to be covered, the method of traditional engineering education, to skills that students should have upon graduation in the form of student learning outcomes [2]. Furthermore, the Accreditation Board for Engineering and Technology (ABET) incorporated problem solving, systems thinking, and teamwork into their student outcomes criterion for undergraduate program accreditation [3,4]. To meet these new standards, approaches to instruction that include learner-centered methods can be incorporated. Both project-based learning (referred to here as PjBL for clarity) and problem-based learning (referred to here as PbBL for clarity) meet these requirements; examples of both PjBL and PbBL will demonstrate how these instructional methods have been and can be used in science and engineering classrooms to fulfill these new standards.

1.1. Defining Project-Based and Problem-Based Learning

PjBL and PbBL share some similarities [2]. Both utilize teamwork to solve real-world problems, most of which are cross-disciplinary; cross-disciplinary activities could involve working across subject areas (e.g., mathematics and chemistry), across subdisciplines within a specific subject area (e.g., civil engineering and mechanical engineering), or both.

Additionally, the problems or projects may be semi-structured or open-ended, depending on the course and student level.

However, PbBL and PjBL also differ in a few key ways [2,5]. PbBL uses semi-structured problems that can last a few class periods to a few weeks. Students usually work in teams with a mentor (such as a teaching assistant or an older student) to find answers to real-world problems. PbBL shares many of its core tenets with the engineering principle of design, which is already taught as part of the engineering curriculum [2]. PbBL is "process-oriented" [2] (p. 10); the problems are structured to guide students to understand the process of solving problems [2,5].

Unlike the problems of PbBL, the projects in PjBL may last a few weeks, an entire term, or a year, depending on the course and program structure. The term "project" is widely used in engineering, so students are able to make connections to what engineers actually do [2,4,6]. A key tenet of PjBL is that the project must be real and important and something that a professional would actually do or consider [7]. Additionally, PjBL is "product-oriented" [2] (p. 10); the projects in PjBL focus on students learning as they create a product [2,5] motivated by a driving question and/or sub-driving question [8]. Table 1 summarizes the key similarities and differences between PjBL and PbBL.

Table 1. Similarities and Differences Between Project-Based and Problem-Based Learning.

Both	Project-Based	Problem-Based
Utilize collaborative teamwork	Longer-term	Shorter-term
Use technology	Focus on understanding and/or modeling real-world phenomena	Focus on solving real-world problems
Use cross-disciplinary problems or projects	Product-oriented	Process-oriented
Mentors or members of the community as partners	Driving question/student sub-driving question	Driving problem/ student assumptions
Require scaffolding	Benchmark lessons	Scaffolding problems

1.2. Connections to Educational Goals

Perrenet et al. [5] defines three main objectives for education: (1) gaining knowledge for use in a professional setting; (2) gaining skills to build on one's knowledge; and (3) development of "professional problem-solving skills" (p. 346). Skills (1) and (3) align with ABET's student outcomes and the gaps noticed by engineering professionals [1–3]. As defined previously, both PbBL and PjBL focus on real-world applications and building knowledge, and both often utilize open-ended problems that increase students' problem-solving and teamwork skills [2,4–7,9–11]. Thus, both PbBL and PjBL can help educators meet educational objectives for building professional skills by facilitating understanding and deep content knowledge as opposed to covering a checklist of topics [2].

PjBL is learner-centered rather than student- or teacher-centered [7]; "learner-centered" focuses instruction on what the student is learning rather than on the teacher as the "sage on the stage" or the student as a consumer [12]. Using PjBL allows students to have conversations—with each other and with the instructor—that allow classroom emphasis to be on transformative conversations rather than on transmission of information from instructor to student [7]. In studies that looked at retention rates when implementing program-wide PjBL, Savage et al. [4] reported a 65 percent retention rate from first to second year, compared with a prior retention rate of less than 50 percent. Mills and Treagust [2] cited a lower dropout rate among first years at a university in Denmark that used PjBL than at comparable schools with traditional programs (20 to 25 percent dropout versus 40 percent dropout).

PbBL is also associated with positive student learning experiences. By using real-world applications, students often have higher motivation to participate in and engage with the material [5], and qualitative student feedback shows that they enjoy PbBL courses and feel that they learn from these experiences [2,13]. Students also show similar or better conceptual gains after PbBL when compared to traditional lecture courses [10,11,13,14]. Additionally, students learn to work on professional teams, with each bringing different skills to solve the problem [11,13,14].

While both PjBL and PbBL have advantages, they also have potential issues. First, PbBL's focus on short-term problems is not reflective of real-world engineering practice, where projects require longer periods of time than a few days or weeks [2]. Students in different PjBL environments at different schools reported lack of clear guidance, lack of preparation for effective teamwork, and instructors that resorted to traditional lectures as problems with the projects [4,6,9]. As engineering builds upon itself, missing one foundational concept can lead to confusion. If the problems are not well-planned, students who learn in a PbBL or in a PjBL environment may develop misconceptions or miss key concepts that are necessary for another, later concept [2,5]. In both PbBL and PjBL, identified studies were small; larger studies are needed with similar outcomes measured to understand the full effectiveness of either PbBL or PjBL.

The research objectives of this study involved: (1) investigating a college engineering professor's first-time implementation of project/problem-based instruction (PBI), and (2) seeing how different the PBI implementation was as compared to a business-as-usual (BAU) engineering mechanics course. The framework for this research is grounded in constructivist theory. Research questions were:

1. To what degree does a first-time PBI implementation change how a course is implemented?
2. How does a PBI Engineering Mechanics course compare to a BAU Engineering Mechanics course?
3. How do PBI students' Engineering Mechanics content knowledge compare to BAU students' Engineering Mechanics content knowledge?

2. Materials and Methods

2.1. Participants

Participants in this study were two Engineering Mechanics (EM) 221 classes (one treatment PBI EM class and one business-as-usual (BAU) EM class) at a university located in south central United States. Engineering students at this institution had the following demographic makeup: 79% male; 21% female; 72.9% White; 10.4% Non-Resident (Alien); 16.7% Other races. Each EM class had similar demographic makeup. The PBI EM 221 instructor was a lecturer at the university with a PhD in Mechanical Engineering and had been teaching EM for 8 years. The BAU instructor was a graduate teaching assistant who had just defended his dissertation in Mechanical Engineering and had taught EM for two semesters.

2.2. Data Collection

This research was a mixed methods study of a quasi-experimental design. Students who consented to the research study were given the Statics Concept Inventory (SCI) [15]; pre- and post-course implementation. The SCI was a 27-item multiple choice assessment encompassing five categories (free body diagrams, static equivalence, forces at connections, friction limit, and equilibrium). Qualitative data involved classroom observations (approximately seven 1.5 h observations per class) and interviews with consenting students from each class. Student interviews were conducted with students from each class during the final weeks of the semester (5 students from the PBI class and 4 students from the BAU class); students from each class volunteered for these interviews. Student interviews included questions regarding their assessment of their EM course in terms of what they were learning, how well they were learning, and how it applied to their major. Interviews were conducted by the researchers and lasted approximately 30 min.

2.3. Data Analysis

Classroom observations were conducted to record the overall class environment (including class layout); course dynamics in terms of lecture-based, interactive, and teacher- or student-centered activities; presentation of materials; and presence of group work. Student interviews were analyzed to determine students' perceptions of their EM course using "category construction" to develop common themes. Each category is "the same as a theme, a pattern, a finding, or an answer to a research question" [16] (p. 178). Quantitative data were analyzed for differences in mean scores (0 to 100 percent) on the SCI between the treatment and BAU class. Due to small sample sizes, nonparametric methods (Wilcoxon signed rank test with continuity correction for paired differences and Wilcoxon rank sum test with continuity correction for between group differences) were used. Percentage correctness for each question by class and pre-test and post-test was used for descriptive comparisons. R version 4.0.0 [17] was used.

3. Results

3.1. Course Change with Incorporation of PBI

The 16-week Engineering Mechanics: Statics course began no differently in 2021 as it had done in 2020. The first mention of project-based instruction to the class began mid-October 2021. Originally, the PBI instructor described to his class that they would be conducting project work throughout the remainder of the term, but later modified his language to problem-based work. Researchers made observations of the class once prior to any PBI work and followed with seven additional classroom observations spanning October through the end of November. We follow with a class material description as outlined by the PBI instructor.

PBI Instructor's Class Material Description

After covering the fundamentals of two- and three-dimensional (2D and 3D) force systems and equilibrium during the first seven weeks of the course, the remaining topics (related to structures, internal and external loading on beams, and area moments of inertia) were covered through three problem-based group assignments throughout the rest of the term. Students were placed in groups of three, with 14 groups created. Each group consisted of three students who were racially diverse and had non-uniform GPAs. The first problem was a footbridge design problem covering the topic of trusses, the second problem was related to the analysis of frames and machines, and the last problem covered several topics related to beam design (including analysis of distributed forces, drawing shear force and bending moment diagrams, and calculating centroid and area moments of inertia). All posed problems can be found in Appendix A. For all problems, the students were expected to submit a 6–8 page report prepared according to sound technical writing guidelines. To help students with report writing, the instructor provided a sample template and some links to external resources. The reports were graded based on organization and structure, analysis, and conclusion and discussion. An example group problem response is located in Appendix B.

For Problems 1 and 2 (Appendix A), students were given about one week to complete the work after the lecture in which the topic was introduced. Problem 3, however, was progressively introduced given that it was related to multiple major topics. Therefore, students were expected to analyze the problem in steps as the relevant topics were taught in class. Overall, they were given about 2 weeks to complete the work and submit their report. Unlike Problems 2 and 3, the solution to Problem 1 could be different for each group depending on the assumptions they made about the live load on the bridge (e.g., the number of people present at the same time on the bridge, their weight, and their location on the bridge).

3.2. Comparing PBI Class with BAU Class Implementation

Both the BAU and PBI classes lasted approximately 75 min, twice per week. Seven classroom observations were made of each classroom during the timeframe of mid-October to the end of November 2021. Seventy-four students were enrolled in the PBI section of Engineering Mechanics (EM): Statics course as of the end of September 2021; 49 students remained enrolled at the end of October, and 42 students were enrolled at the end of the term. Seventy students were enrolled in the BAU EM section as of the end of September 2021, 65 students remained at the end of October, and 52 students remained enrolled at the end of the term.

BAU Class—Seven classroom observations were made of the BAU course during mid-October through the end of November. The BAU course was held in a middle-sized classroom (capacity of around 80 students), with one projector and a large whiteboard at the front of the classroom. The instructor podium was immediately to the side of the projector screen at the front. The instructor projected course notes in PowerPoint, which he posted prior to class for students.

The instructor began each class with course announcements and reminders, then went through the day's slides. Students were able to take notes that the instructor added to the slides as he spoke. The instructor would provide background on the topic, connecting it to students' prior knowledge. After presenting the foundational knowledge, the instructor would work through an example provided on the slides, adding details as he discussed how he would solve the problem. He then provided a similar problem and gave students time to work through it on their own or with others. Students worked independently, though some students would check answers with others near them.

During one of the observations, there were approximately 55 students present as the instructor discussed steps for solving problems with frames and machines and how these were similar to trusses. He continued to illustrate a problem that involved the summation of moments and questioned students regarding the meaning of a negative moment (i.e., sign determines clockwise versus counterclockwise motion). Thirty minutes into class, the instructor had students working on a problem at their seats. The student work lasted about 15 min and the instructor spent the remaining class time working on a machine problem. When going over the problem, the instructor asked students for answers to each step. Students would ask questions for clarification or connection to other topics; one observation day yielded 29 student-initiated questions. Each class observed followed this same pattern, with variations in the number of examples presented based on topic and time needed.

PBI Class—The PBI classroom was located in a large auditorium with a board at the front of the room where the instructor resided. Projections of class notes and EM problems were shown on two screens in the front (one located on the left hand side of the room and the other on the right). During one observation, there were approximately 43 students in attendance and the instructor described how students would be working on projects throughout the rest of the term. He proceeded to introduce a statics trusses problem to the class. He asked students to draw a free body diagram and to begin the design phase. He explained that they would need to make assumptions about the problem in order to solve it. Approximately 40 min into these introductions of the problem, he allowed students to work on the problem in their assigned groups as he circulated the room answering questions. The PBI instructor also had a teaching assistant who circulated the room answering questions. This group problem-solving time lasted 25 min. Whole class discussion of the problem comprised the remaining 20 min of class.

The next class observation began with the instructor reviewing and practicing a statics problem (trusses). Ten minutes in, he requested that students identify "zero force members" in the given problem and to discuss this with their neighbor (group member). Six minutes later he showed the class a video of a real-life situation with the Oregon/Vancouver bridge. After the video, students were to conduct group work to determine various forces; this lasted about 15 min. Whole class discussion of the found forces continued for the remaining 45 min of class.

Each class observed was implemented in much the same format: whole class practice and review sprinkled with some questions, and about 15–25 min of group work, usually towards the end of class, to work on the current class EM problem.

Interviews with PBI and BAU Students

Student volunteers were interviewed from each class concerning their views of their EM course regarding their learning experience and how it might apply to their major or future career. Each interview lasted about 30 min.

Four BAU students volunteered to be interviewed. For these students, three themes emerged: (1) Students felt the course was well structured, (2) Homework problems proved to be challenging, and (3) Students felt the course prepared them for their future coursework and career.

All BAU students interviewed mentioned the example and practice problems demonstrated during class. The students felt that the course was structured well and that the instructor presented material at a good pace:

> "I think the class is structured very well . . . "

> " . . . [I] think [the instructor's] class has been not too stressful but at a good enough pace that I've learned pretty quickly."

Students thought the course would be beneficial for future courses and careers. They also were proud of being able to learn the material. However, some students mentioned struggling with the homework and exams:

> " . . . it feels good to get, like, the fundamentals down. . . . feeling as though I have a good and solid understanding of the basics makes me feel ready and prepared to go to more advanced stuff."

> "I feel like this will actually benefit me in the future for classes and then a job also. So I feel like this is [an] important class for that. And not just getting a good grade, but actually understanding everything is important."

> "I think the most difficult part is studying for the multiple choice on the exams because there's no partial credit on that. So it's all or nothing."

> "Generally, the only part of the class that gives me a bit of a headache is the homework because there's, of course, not as much feedback and it doesn't count as much as the exams as a part of the grade, but they can be pretty tricky problems."

Five PBI students volunteered to be interviewed. Three themes also emerged with the PBI students: (1) Students separated the course into the test-based instructional units versus the PBI units (and gave preference to the latter), (2) Struggles with the course occurred mainly during the first half prior to PBI, and (3) Students reported how the PBI work enhanced their understanding.

For the PBI students, each interviewee described class before PBI and after PBI. Generally, the actual class structure remained largely unchanged. What did change was the assessment. Prior to PBI, traditional tests were given as assessment, but once students began their PBI problems, the problems themselves became the assessment piece and students worked on these problems in groups of three. Students described the change in the following ways:

> "The first part, the first like two months this semester, we did more like test-based learning. So we took like quizzes and then we had to test; and then since then we've done more, like, Project Based Learning where he's given us, like, a bigger, bigger problem to solve and then we had to write a report on the, like, our solution that we came up with the problem and some of those projects have been group based."

> "It started out okay, but I got lost about halfway in unit one, and stayed that way until the very end of unit two. But more recently, especially since we started working in groups more, have kind of felt more caught up and aware of what's going on."

Similar to the BAU class, PBI students reported struggles. However, these reported struggles were prior to the project work.

> "I struggled a lot with the material before the second exam, which had to do with the sum of forces. It took me a while to visualize the problem and visualize which forces corresponded to which, like, distances from the figures that were given."

PBI students claimed the PBI coursework was beneficial.

> "I think the projects are beneficial because I've gotten, like a deeper understanding about the topicversus, like, doing the testslike the projects, you know, you really have to understand the problem in order to solve it and then write the report about it."

> "The projects have been more beneficial to me personally, because sometimes I, like, don't do well under the pressure of the exam. Like, I'm, I just get too nervous as most people get nervous for exams. So I'd say, like, the projects have been beneficial to my learning because it's given me more time to figure out how to do the problems, like, myself without, like, the, like, added pressure of, like, the timed part of the tests because he usually gives us, like, a week or a little longer for the projects."

3.3. Comparing PBI Class and BAU Class Content Gains

After removing incomplete and duplicate attempts, 34 BAU and 49 PBI students completed the pre-test; 22 BAU and 41 PBI students completed the post-test. A total of 17 students from the BAU course and 37 students from the PBI course completed both SCI tests (see Table 2).

Table 2. Complete case analysis of inventory scores.

	Pre-Test	**Post-Test**	**Change (Post–Pre)**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
BAU (n = 17)	23.75 (10.64)	33.99 (16.42)	10.24 (13.19) *
PBI (n = 37)	34.63 (14.77)	42.94 (16.76)	8.31 (15.43) *

* $p < 0.05$, Wilcoxon signed rank test with continuity correction

Analyses showed a significant difference in pre-test scores between courses ($p = 0.0059$); therefore, change scores for the two classes were compared. There was no significant difference in change scores between the PBI and BAU courses ($p = 0.46$). Within-course analyses showed significant gains from pre-test to post-test for both courses (see Table 2).

Because only complete cases were used for comparison, students with partial cases (pre-test or post-test only) were compared to students with complete cases to check for differences within each course. Pre-test scores were not significantly different between the students who completed only the pre-test and who had complete data (BAU $p = 0.33$; PBI $p = 0.76$). This held for the post-test comparison as well (BAU $p = 0.55$; PBI $p = 0.63$).

Item analysis showed that both the BAU and PBI courses had the highest proportion of students answering Question 17 (free body diagram) correctly on both the pre-test and the post-test. Question 15 (forces and friction) was lowest on the pre-test for both courses, while Question 22 (forces and friction) was lowest on the post-test for both courses (see Table 3).

Table 3. Item analysis by course and test.

	Pre-Test Item; *n* (%)		Post-Test Item; *n* (%)	
	Minimum	**Maximum**	**Minimum**	**Maximum**
BAU (n = 17)	10; 0 (0) 15; 0 (0)	17; 11 (64.7)	10; 1 (5.9) 22; 1 (5.9)	17; 12 (70.6)
PBI (n = 37)	12; 2 (5.9) 15; 2 (5.9)	17; 26 (76.5)	15; 3 (8.8) 22; 3 (8.8)	17; 30 (88.2)

When comparing percent correctness by item, both courses had Item 17—an item on partial free body diagrams and loads—as the highest scoring, which was consistent from pre-test to post-test. Students in both courses struggled with Items 15 (forces and friction) and 22 (also forces and friction). The BAU class had difficulty with Item 10 (forces and friction) on both the pre-test and post-test, while Item 12 (forces on pins/connections) was low for the PBI class on the pre-test.

4. Discussion

We begin this section with the limitations of this study. While 94 students were enrolled across both courses at the end of term, only 54 students—17 from the BAU section and 37 from the PBI section—completed the pre-test and post-test, making this a small sample size. Another limitation concerned the differing dropout numbers between the two sections. By the end of October, the BAU class had 5 students drop out, while the PBI course had 25. Finally, because PBI did not begin until mid-semester, many of the PBI students had dropped the course prior to commencement of the PBI work; only an additional 7 dropped once the project work began. Therefore, we do not know how many students might have stayed in the PBI class if the PBI work had begun from the class onset.

We follow with discussions for each research question (RQ).

4.1. Discussion for RQ1

To what degree does a first-time PBI implementation change how a course is implemented? In terms of preparation for this new direction of his class implementation, the PBI instructor read papers, books, and sought advice from project-based researchers. Although the original intent of the PBI instructor was to make his EM class into a PjBL classroom, he found PbBL was more conducive to this transition from his traditional BAU method to a more constructivist method. This realization that he actually was doing PbBL (focusing on students solving real world problems, working in groups for short term periods of time with a focus on process rather than product) instead of PjBL did not take place until the end of the term. Within his class, he mainly had used the language of PjBL with his students; hence, during interviews that was also the type of language the students recited. The actual PBI course instruction did not necessarily change from prior teaching (i.e., pre-PBI student work); the assessment piece was the change agent during the second half of the course. No longer were standard quizzes and tests administered, but instead three problems were given that students worked in collaborative groups to solve.

As noted earlier, students expressed how they had struggled with the course material during the pre-PBI time period of the course, calling it the "test-based instructional" portion. However, this all changed for them as they engaged in the collaborative PBI work, which they claimed enhanced their understanding of engineering mechanics. Such a change empowered the students, creating a path towards a more student-centered approach to learning [18]. Boylan-Ashraf [18] provides seven years of data that demonstrates how "student-centered pedagogies in teaching IFEM (introductory fundamental engineering mechanics) courses should be emphasized over traditional, passive, teacher-centered pedagogies" to improve student understanding of engineering fundamentals on a larger scale (p. 27). Similar sentiment was discussed by Mills and Treagust [2] as well as the Accreditation Board for Engineering and Technology [3].

4.2. Discussion for RQ2

How does a PBI Engineering Mechanics course compare to a BAU Engineering Mechanics course? As evidenced by the classroom observations, there were largely no differences in the actual daily instruction when comparing the two EM sections (BAU and PBI). Both had similar formats—introduction of a new concept/problem and working through a problem as a class followed by individual or paired/group work at the students' seats. Instructors would circulate around the class aiding and answering questions. As evidenced from the interviews, the difference was in the assessment piece, where the PBI course replaced tests with three collaborative group problems. PBI students genuinely preferred the problem-based format of assessment and felt they understood the material better through their collaborative group work.

During interviews, both PBI and BAU students reported struggles with exams at the beginning of the term (first half of semester). There may have been more stress for the students in the PBI section at the beginning of the term regarding test performance because 25 students dropped the PBI class as compared to the 5 BAU students who dropped by mid-semester.

Both sections had students describing the strengths of their EM class sections where a BAU student described how it felt good to get "*the fundamentals down. . . . feeling as though I have a good and solid understanding of the basics*" as compared to a PBI student stating "*I think the projects are beneficial because I've gotten, like, a deeper understanding about the topic—versus, like, doing the tests— like, the projects, you know, you really have to understand the problem in order to solve it and then write the report about it.*"

4.3. Discussion for RQ3

How do PBI students' Engineering Mechanics content knowledge compare to BAU students' Engineering Mechanics content knowledge? Despite PBI students' higher post-test scores on the SCI, when adjusting for pre-test scores, the two courses had similar gains. When comparing percent correctness by item, both courses had Item 17—an item on partial free body diagrams and loads—as the highest scoring, which was consistent from pre-test to post-test. Students in both courses struggled with Items 15 (forces and friction) and 22 (also forces and friction). The BAU class had difficulty with Item 10 (forces and friction) on both the pre-test and post-test, while Item 12 (forces on pins/connections) was low for the PBI class on the pre-test. Students in both courses struggled with similar topics on the SCI. This was especially true for forces and friction test items. According to Steif and Dantzler [15], students often incorrectly presume "a friction force is at the slipping limit (μN), even though equilibrium is maintained with a friction force of lesser magnitude" (p. 364). Similarly, BAU and PBI students performed best on free body diagram test items.

5. Conclusions

With the SCI assessment used to measure content understanding, no significant differences were observed between the PBI and the BAU EM sections. However, in future studies, it might be worthwhile to pose a problem to students (in both PBI and BAU sections) where assumptions would need to be made in order to solve the problem, and students would need to write out their solution explaining the assumption choice and their problem solution. In other words, the measurement should utilize a more real-world type of performance assessment rather than a multiple-choice test. Boaler [19] found in comparing a PjBL approach to a BAU/traditional approach to teaching, that students in the PjBL tended to score just as well as BAU students on standard assessments involving basic recall, multiple choice test responses, and non-contextualized mathematical problems. However, on assessments that were contextualized where students would need to make assumptions and apply their mathematical knowledge to real world situations, the PjBL students outperformed the BAU students.

Only 56% of the original PBI students completed the course as compared to 74% of the BAU students. This stat is a bit misleading, because at the October mark, 66% of the PBI students remained and only 7 more students dropped the class by the end of the term, whereas 13 BAU students dropped their course between October and the end of the term. A future study ought to compare PBI and BAU classes where the PBI class begins the PbBL immediately from the start of the class instead of waiting until mid-semester. Perhaps the large class student attrition in the PBI section might have been prevented if this were the case as documented by [2].

Finally, it should be noted that as a first step into PBI with his EM class, the instructor noted the benefits to moving his course into a more constructivist format and continues to seek ways to create a PBI environment that will engage and advance his students EM understanding in a manner that will extend beyond their EM course.

Author Contributions: Conceptualization, J.A.W. and F.T.; methodology, J.A.W. and J.A.D.; formal analysis, J.A.D. and J.A.W.; data curation, J.A.D. and J.A.W.; writing—original draft preparation, J.A.D. and J.A.W.; writing—review and editing, J.A.W., J.A.D. and F.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Human subjects research approval was obtained through the University of Kentucky Institutional Review Board (IRB), protocol # 72599.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy concerns.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

1. Footbridge Design Problem [20] (p. 397)

Description: Design a footbridge for crossing a small stream. The bridge is intended for residential use only. The bridge consists of two identical trusses, spaced 3 ft apart (see Figure A1). For ease of fabrication, each truss is to be constructed of one size of welded steel pipe, with all members having the same 3 ft length. The 100 lb forces represent the dead loads. You are to specify the maximum safe live load for the bridge and the diameter of pipe to be used. Make all the necessary assumptions about the magnitude, location, and possible live loads that might exist on the bridge.

Method of Analysis: Use a combination of the method of joints and the method of sections.

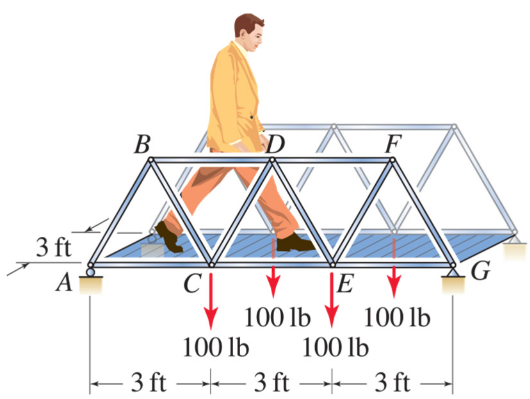

Figure A1. Footbridge.

2. Component Analysis Problem [21] (p. 83)

Description: The truck shown in Figure A2 is used to deliver food to aircraft. The elevated unit weighs 2000 lb with the center of gravity at G.

Derive the expression for the force in the hydraulic cylinder AB as a function of θ (the angle that member FD makes with the horizontal).

Plot the magnitude of the force over the range $0^\circ \leq \theta \leq 45^\circ$ and discuss your observations.

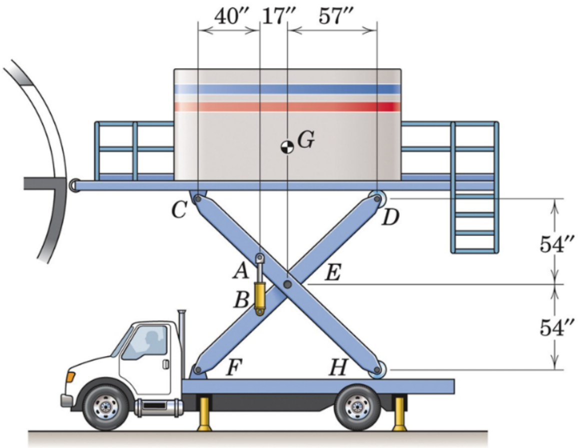

Figure A2. Truck delivering food to aircraft.

3. Beam Selection [22] (pp. 545–546)

Description: A manufacturer wants to design a hydraulic floor crane that can lift an engine with a maximum weight of 5300 N (see Figure A3). Two choices are considered for the top beam (ABC): a T-beam and a C-beam, as shown in Figure A4a,b, respectively. The beams are made of steel (uniform weight distribution, $\rho_s = 8000\ \text{kg/m}^3$). Perform a complete analysis of the beams (include the shear force and bending moment diagrams), calculate the maximum bending stress and its location, and provide your recommendation on which beam the manufacturer should use to design the crane.

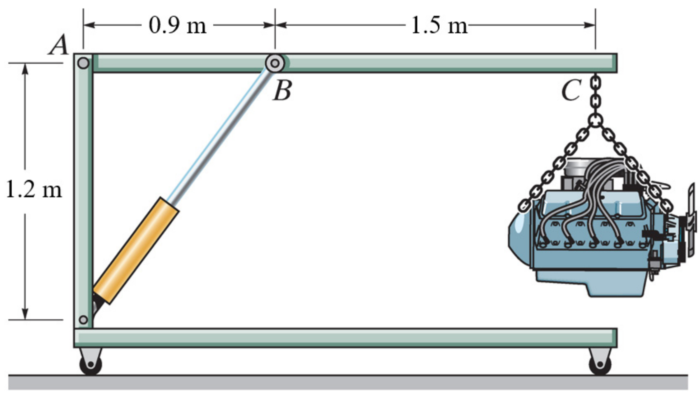

Figure A3. Hydraulic floor crane lifting an engine.

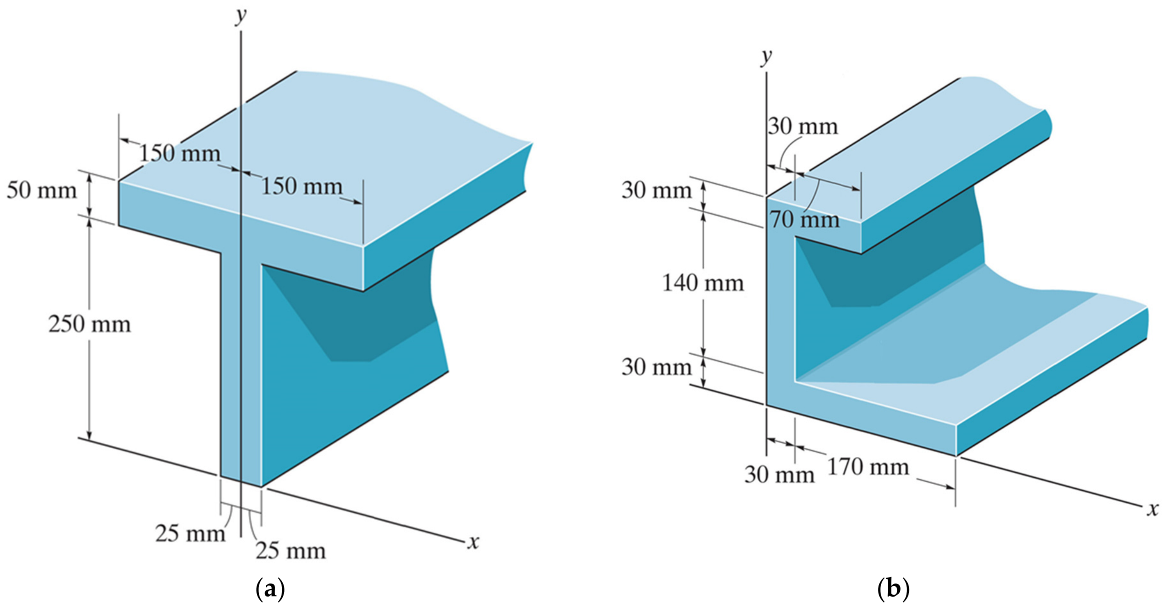

Figure A4. (**a**) T-beam. (**b**). C-beam.

Appendix B

Appendix B illustrates an excerpt from a group report for Problem 1 (Footbridge Design) in which the students have talked about the assumptions they have made, the solution strategy they have followed to solve the problem, and a sample solution.

Example of a Student Group's Solution with Assumption for Problem 1.

Assumptions

To begin the problem, we made several assumptions concerning where the weight would be distributed on the bridge. First, we started with a maximum of three people on the bridge at a time. This was based on the assumption that a person takes up a 3 by 3 foot square and the bridge is 3 by 9 feet. We assumed that each person could weigh up to 225 lbs and considered this reasonable because the average weight of a person is around 180 lbs. We said that the weight would act at the center of each bottom horizontal member and then be distributed to each of the eight bottom joints on the truss.

Based on the problem description, we assumed that point G was a pin support and point A was a roller. We also assumed that no forces would act in the x direction.

Solution Strategy

1. Draw free body diagram with the entire truss being the system
2. Solve for external reactions at roller A and pin G
3. Cut through members BD, CD, CE
4. Use method of sections
5. Find the moment about point C to find BD
6. Sum the forces in the y-direction to solve for CD
7. Sum the forces in the x-direction to find CE
8. Use method of joints to find the remaining members
9. Choosing A:
    a Draw a FBD for joint A
    b Sum forces in the y-direction to solve for AB
    c Sum forces in x-direction to solve for AC
10. Draw a FBD for joint B and solve for BC by summing forces in the y-direction
11. The structure is parallel so AB = FG and BC = FE etc ...
12. Obtain the force in CE
13. Plug in max tensile strength for decided diameter of steel pipe for member CE
14. Work backwards to solve for weight

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