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The Wooden Bike Frame Challenge: Learning Statics Through Hands-On Design

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Introduction

Theoretical concepts in Statics, which is typically a second or third semester course in mechanical engineering programs, build in complexity from isolated particles, then to rigid bodies, and finally to structures formed by multiple rigid bodies. Structural analysis, otherwise known as "frames and machines," is therefore one of the more complex topics covered in the course because it integrates prior knowledge of particle and rigid body equilibrium (RBE) with new concepts like two-force members and visualizing internal loads at cross sections. Traditionally, students become proficient in structural analysis by solving textbook problems that may inherently point them towards a particular method of analysis such as method of joints (MOJ) versus decomposition into multiple RBE expressions. In actual practice, structural analysis is less straightforward; and mechanical engineers must thoughtfully examine a real-world structure to determine the best method of analysis and likely failure location(s). When faced with more open-ended structural analysis problems, students frequently make incorrect assumptions about two-force members, action-reaction pairs, and internal loads that can lead to inappropriate or inaccurate analyses.

Problem- and Project-Based Learning in Statics

Prior studies in undergraduate engineering education have introduced problem- and project-based learning (PBL) experiences for Statics courses that involve design challenges [1-8]. Collectively, this body of research provides valuable exemplars about how PBL learning opportunities can advance students' engineering knowledge and skills, yet there remain two substantial limitations. First, the prototyping component of research that describes student learning during statics PBL exercises often falls short of actual practice by limiting students to scale model designs in craft grade materials, e.g., table-top sized bridges constructed from balsa wood or craft sticks [3, 4, 6, 9]. While economical and logistically efficient, scale model designs do not reinforce industry-relevant design and fabrication skills, such as computer aided design (CAD), computer aided manufacture (CAM) and machine shop skills. Moreover, scale models cannot be subjected to full-scale loading conditions, and this further disconnects the exercise from engineering practice where full-scale loads are simulated experimentally or analytically. A second issue with existing research on student learning through Statics PBL experiences is that problem solving is not significantly different from textbook scenarios, thereby allowing students to use procedural rather than conceptual approaches. More specifically, these types of closed ended problems provide students with the appropriate method of analysis and region(s) of failure rather than making affordances for students to discern which method(s) of analysis are most appropriate and at which region(s) the design might fail. Previously published bridge design experiences – of which there are a multitude [2-7] – inherently suggest method of joints (MOJ) or method of sections (MOS) approaches for student problem-solving, with all rigid bodies being two-force members connected by pins, and failure locations in the middle of the span. In actual practice, mechanical engineers are more likely to design machines which are not strictly composed of two-force members and have non-obvious failure locations. There is therefore a need to provide students in Statics with learning experiences that allow for open-ended, conceptual (rather than procedural) approaches to problem-solving.

Effective Problem-Solving Approaches in Engineering

Supporting and improving students' analytical and problem-solving skills is critical for producing engineering graduates who can generate technological solutions that are safe, ethical, and meet the needs of end users [10]. As a fundamental engineering course, Statics requires students to develop and use disciplinary analytical problem-solving skills that should go beyond recitation of memorized concepts and procedures required in rote, closed-ended problems. In fact, procedural problem solving in statics may only require students to notice patterns in the problem statement and apply previously used procedures with specific rules to compute a numerical answer. Such problem-solving strategies can mask students' actual knowledge and skills related to structural analysis since determining the correct answer may be a result of memorized procedures rather than true application of concepts or mathematical skills. Previous research has shown that students may understand physics concepts but make errors in mapping knowledge to problem states [11, 12].

Development of effective open-ended problem-solving skills demands engineering students develop a repertoire of mental strategies that integrate statics concepts with relevant mathematical techniques. Problem-solvers use both cognitive and metacognitive processes to integrate representations and develop solutions [10, 13]. Cognitive processes are the heuristic techniques that problem-solvers use to activate relevant concept knowledge, consider potential solution paths, focus attention on relevant details, and integrate information during problem-solving processes. During the act of problem-solving, students must make sense of and integrate multiple representations, including numerical, symbolic, and diagrammatic to determine viable paths to solution. Metacognitive processes are also used during problem-solving to monitor goal progress and evaluate the potential solution [14].

Prior research indicates that novice and expert problem-solvers apply different cognitive and metacognitive strategies to decompose and solve problems [15]. Novices typically use heuristics that emphasize means-ends analysis, a backwards problem-solving approach that uses similar problems (e.g., previously worked textbook problems) to determine what the solution should look like. On the other hand, experts organize problem-strategies around deeper conceptual principles, integrate and apply representations salient to the problem, and consider multiple potential paths to solution [16, 17]. Moreover, experts can leverage metacognitive processes to reflect on their progress and use self-explanation in sophisticated ways that support convergent thinking about solution paths [15]. If the goal is to produce competent professional engineers, then engineering educators should prioritize complex design problems and projects that are open-ended, require flexible application of disciplinary knowledge and skills, and critical consideration of multiple potential solution paths [18].

Our Intervention: The Wooden Bike Frame Challenge

In this study, we implemented a novel PBL exercise called the Wooden Bike Frame Challenge, a multi-week, team-based project embedded within a semester long (15 week) Statics course. The learning objectives for the Wooden Bike Frame Challenge were as follows: (1) to apply structural analysis concepts to predict the likelihood of failure of a full-scale bike frame; (2) to reinforce product design process and communication skills acquired in prior semesters; (3) to strengthen computer aided design (CAD) and computer aided manufacture (CAM) skills, specifically for multi-part assemblies with manufactured and stock components.

The challenge focused on strengthening students' skills in structural analysis, design, fabrication through the construction and testing of a full-scale wooden bike frame. The design challenge was purposefully open-ended, allowing students to conceptualize, analyze, and prototype bike frame designs that require different structural analysis approaches (Figure 1). Scaffolds and deliverables for this PBL exercise were designed to complement course learning objectives while reinforcing essential engineering design practices. Nearly all deliverables for the PBL were team-based (Table 1), and, collectively, these deliverables constituted 10% of the total course grade.

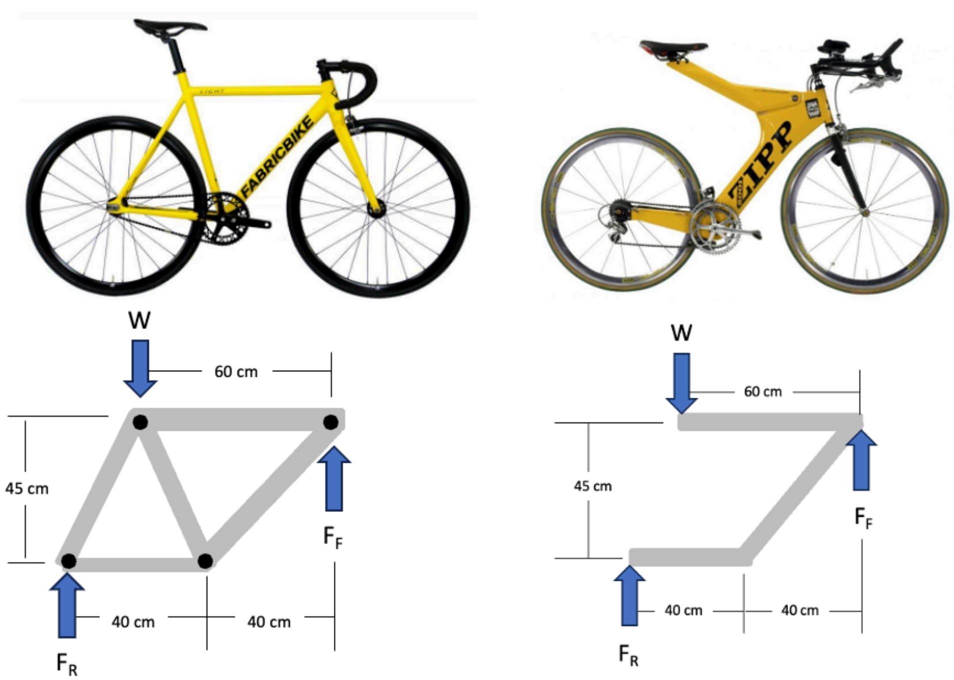

Figure 1: Bike-themed open-ended structural analysis homework problems that asked students to identify likely locations of failure for a bike frame. (left) A bike frame consisting of all two-force members that could be analyzed with MOJ or MOS; and (right) a frame with no two-force members that would require multiple RBE analyses.

The design challenge launched during week 7 of the course (see Table 1), which allowed for structural analysis to be introduced in the lecture portion of the course before students were expected to apply those skills to the project. Individually, all students completed online and in-person safety training for the carpentry skills needed for the project. In teams, students then completed a prototyping "warm-up" in which they manufactured a common front fork for their bike using predetermined specifications in engineering drawings. This warm-up also served to introduce students to the carpentry techniques specific to the bike project such as, joinery and use of bolt assemblies. Teams were required to submit a technical brief that documented their prototyping process for the front fork, as well as accounting for each team member's contributions to the final product.

Table 1. Outline of the schedule, learning objectives, and major deliverables for the Wooden Bike Frame Challenge.

Topic	Learning Objectives	Deliverables
Week 7 Orientation & Safety Training	• Learn safety & usage protocols for all workspaces • Complete online safety training to gain access to Studio prototyping spaces • Hands-on training on all major carpentry equipment	• Online quiz (Individual) • In-Person Training (Individual)
Weeks 8-10 Prototyping Warm-Up	• Practice reading engineering drawings • Advance your skills in carpentry & assembly • Gain knowledge of joinery, fits, & fasteners that will be used for the bike frame	• Technical Brief #1: Standard Operating Procedure, Photo, Team member contributions
Weeks 9-15 Bike Frame Challenge	• Generate and select a concept that meets provided design constraints • Apply structural analysis concepts from statics to determine risk of failure for design. Modify design as needed. • Create complete CAD model of multi-part bike frame design • Use CNC techniques to manufacture body of bike frame & assemble using manual techniques • Conduct design validation for most essential metrics of safety, size, and cost	• Technical Brief #2: Metrics, Concepts, & Concept Selection • Structural Analysis • CAD Engineering Drawing Packet • Technical Brief #3: Design Validation Results, Photo • Peer Evaluation

As shown in Table 1, core activities of the Wooden Bike Frame Challenge took place over six weeks and followed an accelerated four-phase engineering design process (EDP), specifically: Phase 1. Problem Definition, Phase 2. Concept Generation and Selection, Phase 3. Prototype Generation, and Phase 4. Design Validation. Emphasis for this project was on Phases 3 and 4, with Phases 1 and 2 being compressed into a single one-week deliverable. For Phase 1, the Project Scope and Constraints (Table 2) were tightly defined by the instructor to conserve prototyping materials and increase the likelihood of developing a structurally sound prototype. Students were tasked with designing a wooden, foot-propelled bike frame that could support an adult sized user (200 lbs.) with a factor-of-safety of 1.5. All bike frames were made on a 4'x4' sized CNC router (FabBot, Forest Scientific) from ½" thick plywood and held together with bolt assemblies (UNC ¼-20). Instructor-recommended wants (see Table 2) prioritized low cost and lightweight designs, guarding against over-engineering by student teams. In Phase 2 of the EDP, student teams were required to generate and sketch three concepts that met the problem definition and then systematically choose one concept to advance into final design.

Table 2: Project scope, constraints, and wants organized by priority for the Wooden Bike Frame Challenge.

Project Scope: To design and build a safe and functional full-scale prototype of a wooden frame bike for adult users that is foot propelled.

Constraints	Wants
• Design composed of ½" thick plywood joined with ¼-20 bolt assemblies • Frame must be cut from 4'x4' sheet of ½" thick plywood using CNC router • Frame must fit two 26" wheels. Front fork must use common design. • Bike must support 200 lb. user with 1.5 FOS for failure of any structural component • Bike must disassemble into standard travel bike bag (50"x32"x9"). • No brakes or drive systems. Design must be foot propelled.	High Priority • Economical – Calculate using provided cost of goods • Lightweight – Weight of bike with wheels Medium Priority • Easy to Assemble – Time to assemble when in bike bag • Comfortable – End-user survey Low Priority • Stylish – End-user survey • Fast! – Optional bike race at end of semester

In Phases 3 and 4 of the EDP, teams created detailed designs for their bike frames, produced a functional prototype, and tested their design against performance metrics. Students generated CAD models (SolidWorks 2021, Dassault Systèmes) of their frame and merged them with provided solid models for the wheels, front fork, and bolt assembly hardware (Figure 2, left). Teams were required to submit complete engineering drawing packets, with assembly drawings and dimensioned parts drawings, as well as 2D cut paths for processing the frame on the CNC router. Students physically assembled their prototypes (Figure 2, right), documenting any deviations from the original design; and this prototype was then used to validate key metrics (Phase 4). Specifically, they were required to validate weight, disassembled size, cost, and assembly time, as well as to proof test the structural integrity of the frame by having one or more team members sit on the bike. Teams that passed the proof test could participate in an optional bike race at the end of the semester.

Figure 2. Example student work for final bike frame design: CAD assembly drawing (left) and assembled prototype (right).

In addition to CAD modeling, Phases 3 and 4 of the EDP required students to perform a structural analysis of their bike frame. This analysis involved students abstracting their frame designs into two-dimensional multi-body structures that were then decomposed into multiple rigid body subcomponents (Figure 3). Students were instructed to consider failure at both "pins" (bolt assemblies) and "members" (frame cross sections). Students were expected to independently determine which location(s) were of the most concern. Prior to this analysis, the instructor provided one example bike frame analysis in lecture and one homework problem (see Figure 1). For the PBL exercise, students were provided with a calculator (MS Office: Excel, Microsoft) that computed factor-of-safety (FOS) for overload of members based on internal loads (normal, shear, bending moment) and basic geometric properties (thickness, width). This calculator was provided because students in Statics have not yet been introduced to Solid Mechanics concepts like stress and Euler beam theory. The load limit for pins was provided in the problem statement, and students were able to compute FOS directly. FOS calculations were used to make design modifications to achieve the 1.5 FOS target (Phase 3) and then to validate structural integrity of the design (Phase 4).

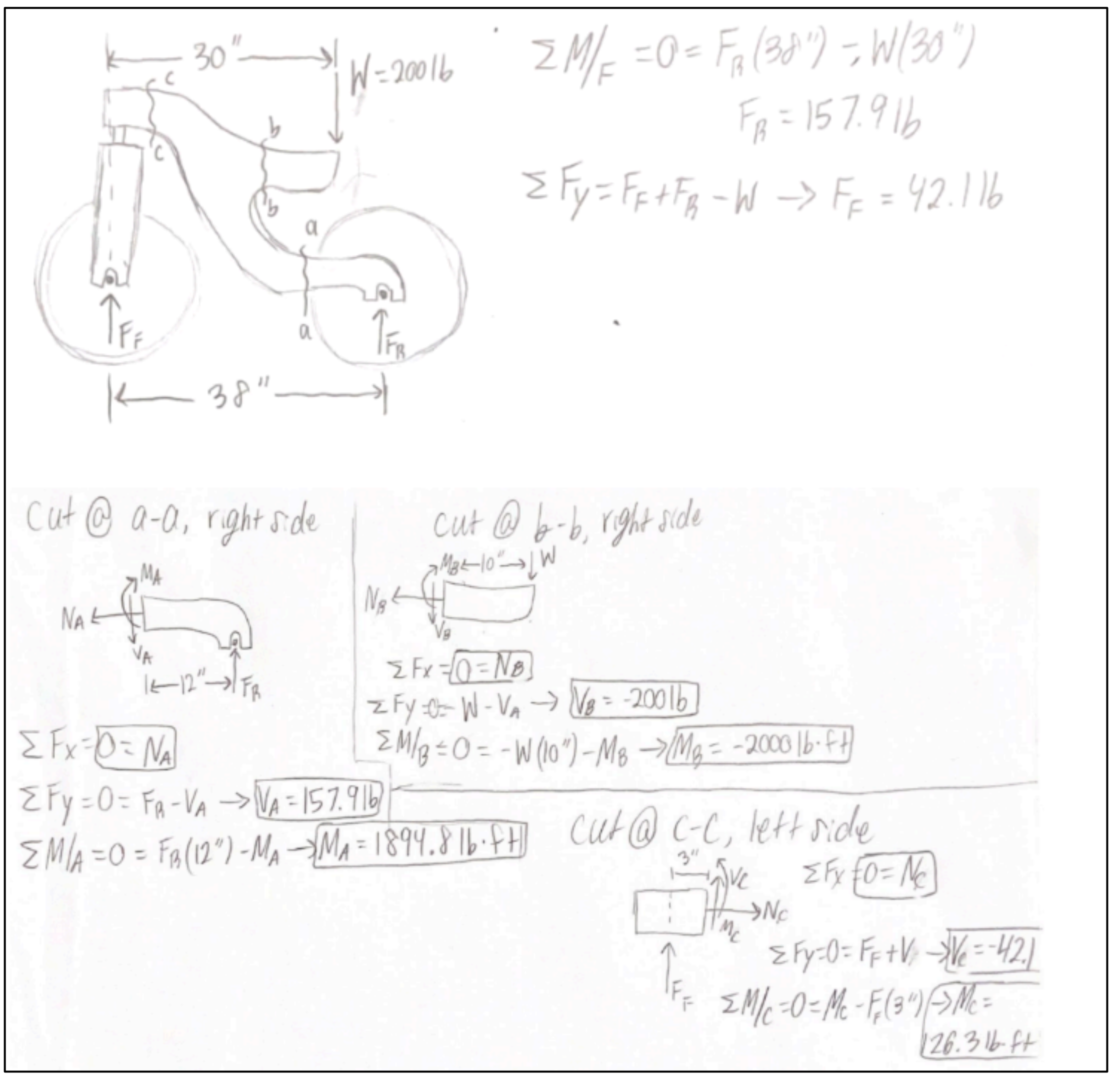

Figure 3. Example structural analysis of student team's bike frame from Figure 2.

We investigated the effectiveness of this PBL exercise in reinforcing students' skills for open-ended structural analysis using a mixed methods approach. The research questions guiding our study were:

1. To what extent was participation in the Wooden Bike Frame Challenge associated with positive changes in students' ability to perform open-ended structural analysis?
2. To what extent was participation in the Wooden Bike Frame Challenge associated with positive changes in students' confidence for engaging in full-scale engineering design?

We collected data from students enrolled in a one-semester Statics course. Data sources for this study included: (1) individual students' pre- versus post-PBL performance on textbook structural analysis problems; (2) accuracy of structural analysis of student teams' bike frame designs; and (3) a voluntary, end-of-term survey of self-reported participation and perceived value of all tasks in the PBL exercise.

Methods

In this study, we used an exploratory sequential mixed methods design [19] to discern changes in students' ability to solve open-ended statics problems and their confidence in using related engineering design skills in a team-based project. Our study relies on qualitative analysis of student performance on exam problems administered before and after the project, their performance on structural analysis of their prototypes during the project, and their responses to an exit survey. Subsequent to qualitative analyses, we performed statistical analyses to determine what quantitative differences existed, if any, in student performance on structural analysis before and after the project. This method allowed us to discern the quality of student learning through convergent data analysis and triangulation.

Context and Participants

The study setting was a single, large-enrollment section of a statics course that enrolled first semester sophomore year mechanical engineering students (N = 155) at a mid-sized university in the Mid-Atlantic region during Fall 2023. For the Wooden Bike Frame Challenge, all students were randomly assigned to one of 37 PBL teams of 4-5 individuals per team. Our study took place during the fifth year of implementation of the Wooden Bike Frame Challenge in this course, during which time the study team continuously refined the project to support student achievement of course learning outcomes. Two faculty co-taught the course. One of the two instructors covered all structural analysis content in the lecture portion of the course and administered the PBL exercise.

Data Sources and Analysis

Three data sources were used the investigate the influence of the Wooden Bike Frame Challenge on students' learning.

Data Source #1: Structural Analysis Exam Problems. We assessed student performance on textbook-style structural analysis exam questions which were administered pre-PBL at approximately Week 12 of the course and again post-PBL during the final exam (Week 15). There were no additional lectures or homework related to structural analysis between these two evaluation periods. Two exam questions (one pre- and one post-) were carefully designed to be equal complexity and point value. Student responses were scored by a single instructor using the same rubric for both problems. The instructor also categorized student responses according to whether they correctly made several fundamental assumptions that were common to both exam problems. These assumptions were: (1) correctly classifying all members in the structure as being two-force or not two-force; (2) decomposition of the structure into multiple rigid body subcomponents, each with appropriate free body diagrams; and (3) identifying and applying action-reaction pairs at pins and other connectors. Numerical scores on exam problems were compared pre- to post-PBL using a paired one-way analysis of variance. The percentage of correct assumptions made by students on each problem was compared pre- vs. post-PBL using a paired chi-square test (JMP Pro 17, JMP Statistical Discovery LLC).

Data Source #2: Wooden Bike Frame Structural Analysis. Each team submitted their bike frame structural analysis as part of the design challenge (see Figure 3). Teams were required to model their bike frame as a two-dimensional structure, subjected to static loads imposed by an adult user (ca. 200 lbs.) sitting on the seat. Students identified the pins (bolt assemblies) and frame cross-sections most at risk of failure. An instructor scored the team submissions using a rubric similar to that used to evaluate student performance on pre- and post-PBL exam problems. The same instructor identified whether teams correctly made the following assumptions: (1) correctly classifying all members in the structure as being two-force or not two-force; (2) decomposition of structure into multiple rigid body subcomponents, each with appropriate free body diagrams; and (3) correctly applying normal, shear, and internal bending moments at a cross sections of interest. Note that the assumptions differ slightly between the exam problems and bike frame structural analysis due to the geometry of the structures being analyzed. Results for the team submissions were analyzed using descriptive statistics (i.e., mean and standard deviation).

Data Source #3: Post-PBL Exit Survey. An exit survey was administered to all students enrolled in the statics course at the end of the term. The survey was voluntary and anonymous, and it asked students to self-report their level of involvement - compared to their teammates - with key tasks for the PBL exercise, including their involvement in structural analysis of the bike frame. The survey asked students about their perceptions of the value of the exercise in reinforcing statics concepts, particularly related to structural analysis, and design and prototyping skills. Students' responses to four-point Likert scale were analyzed using descriptive statistics, and responses to open-ended survey items were subjected to thematic analysis [20].

Results

A robust and representative data set was collected for all elements of our mixed-methods study. All student teams (n=37) completed the Wooden Bike Frame Challenge and submitted the project deliverables. Eighty-three percent (N=128) of all students in the course consented to participate in the study, and pre- and post-PBL exam questions were analyzed for all of these individuals. Among consenting study participants, 86% (n=110) completed the end of term survey.

Students' performance on structural analysis exam problems improved significantly over the time period corresponding to the analysis portion of the bike frame exercise. Pre-PBL scores for structural analysis problems were 63.9% ± 26.3% (M ± S.D., 100% scale) and increased to 75.0% ± 23.5% for post-PBL [$F(1, 127) = 26.087$, p <0.0001]. After the PBL exercise, students were significantly more likely to correctly identify two-force members and apply action-reaction pairs (Table 3).

Table 3. Rates at which students correctly made assumptions on structural analysis exam problems. Comparison between pre- and post-PBL made using paired Chi-Sq (df = 4, *N*=128).

Assumption	Pre-PBL	Post-PBL	Chi-Sq	p-value
2-Force Member	55.5%	78.1%	15.04	<0.001
Subcomponent RBEs	57.0%	60.2%	0.26	0.612
Action-Reaction Pairs	35.2%	52.3%	7.72	0.005

All teams (*N*=37) performed structural analysis calculations for their custom bike frame designs, and the scores across all teams were 85.9% ± 12.1% (*M* ± S.D., 100% scale). In their analyses, 83.8% of teams made the correct assumptions for two-force members, 70.3% for internal loads, and 56.8% for subcomponent RBEs.

Students' self-reported level of participation in the Wooden Bike Frame Challenge varied by task (Figure 4). Students were most consistently engaged in the warm-up carpentry exercise (91.8% reportedly engaged "more" or "same as" teammates), Phase 1 and Phase 2 activities (90.9% and 86.4%, respectively), and Phase 4 design validation (84.6%). They were least engaged in the structural analysis of the bike frame, with 34.6% reporting less involvement than their teammates and 8.2% reporting no contribution at all. Similarly, only 63.7% of students participated in CAD modeling at levels equal to or exceeding their teammates.

As a whole, students reported the PBL exercise strengthened their statics knowledge and reinforced design skills (Figure 5). The vast majority of students either strongly (70.0%) or somewhat (26.4%) agreed that the Wooden Bike Frame Challenge "allowed them to connect statics to real world design." Respondents strongly (42.7%) or somewhat agreed (9.1%) that the PBL exercise "reinforced [my] knowledge of structural analysis," with 93.6% reporting the exercise helped them "determine where structures might fail." The majority of the students agreed that the project reinforced concepts of internal loads (78.2% strongly or somewhat agree), two-force members (68.2%), and free body diagrams (77.3%). Students who participated in the structural analysis portion of the project were significantly more likely to agree that the exercise: (1) "reinforced [their] knowledge of structural analysis concepts" [Chi-Sq(3, N = 110) = 10.42, *p*=0.02]; and (2) "gave [them] additional practice with free body diagrams" [Chi-Sq(3, N = 110) = 10.75, *p*=0.01].

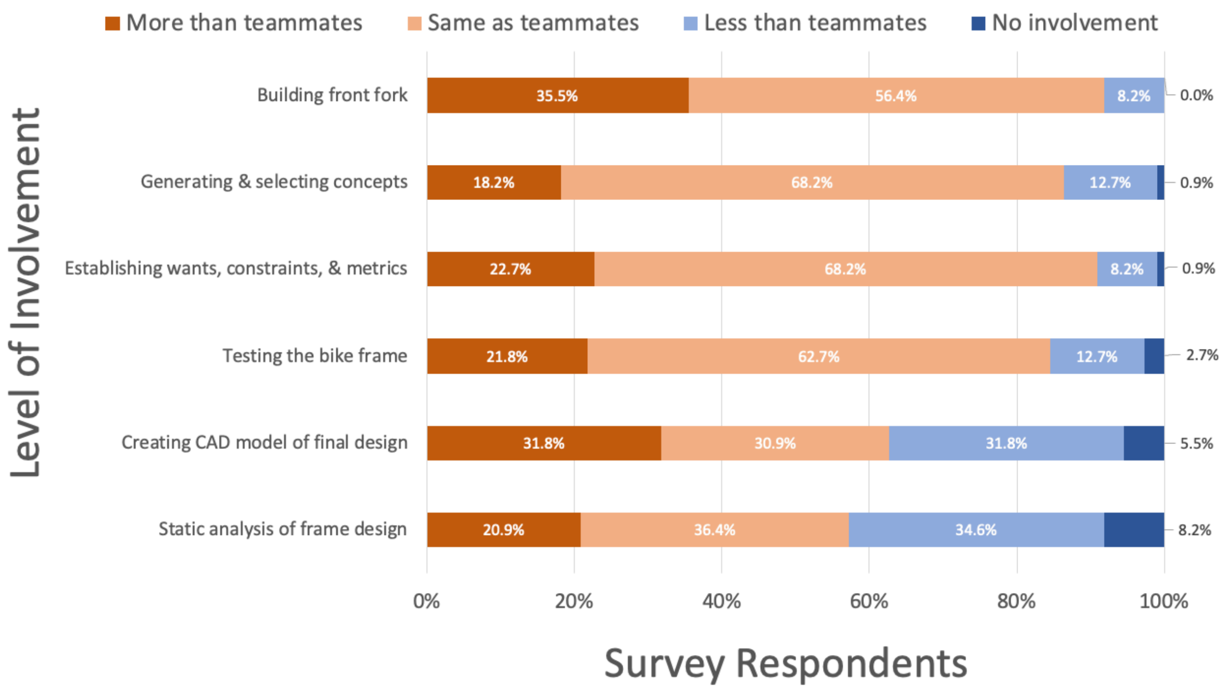

Figure 4. Level of involvement by task for the Wooden Bike Frame Challenge. Data are self-reported by students from an end-of-term survey (*N*=110).

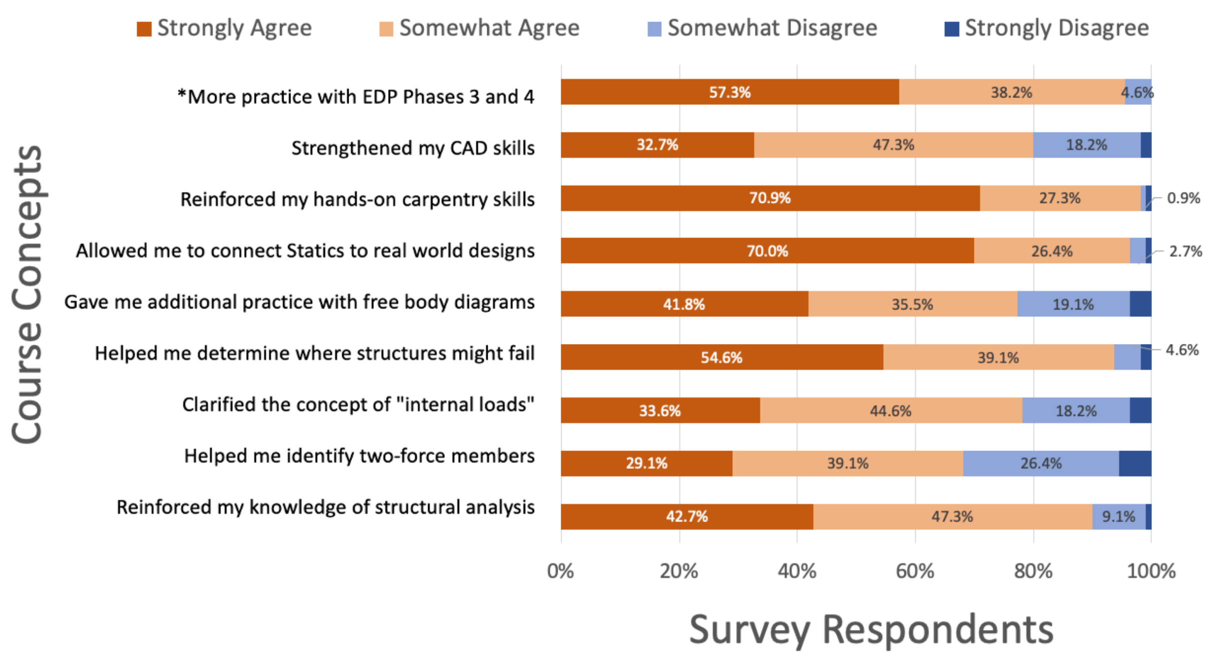

Figure 5. Level of agreement that the Wooden Bike Frame Challenge reinforced course concepts in structural analysis and engineering design. Data are self-reported by students from an end-of-term survey (*N*=110). *EDP = Engineering Design Process.

Students provided valuable feedback on the PBL exercise in the free-response portion of the end of term survey. When asked which specific statics concepts were used for the bike frame challenge, students most frequently cited internal loads (*n*=50), two-force members (*n*=18), free body diagrams (*n*=16), and equilibrium analysis (*n*=16). A breakdown of the statics concepts that were cited in the survey responses is detailed in Figure 6. In the general comments (Table 4), students perceived the project to be engaging (*n*=30), while also indicating that the project timeline was compressed and made the project feel rushed (*n*=16).

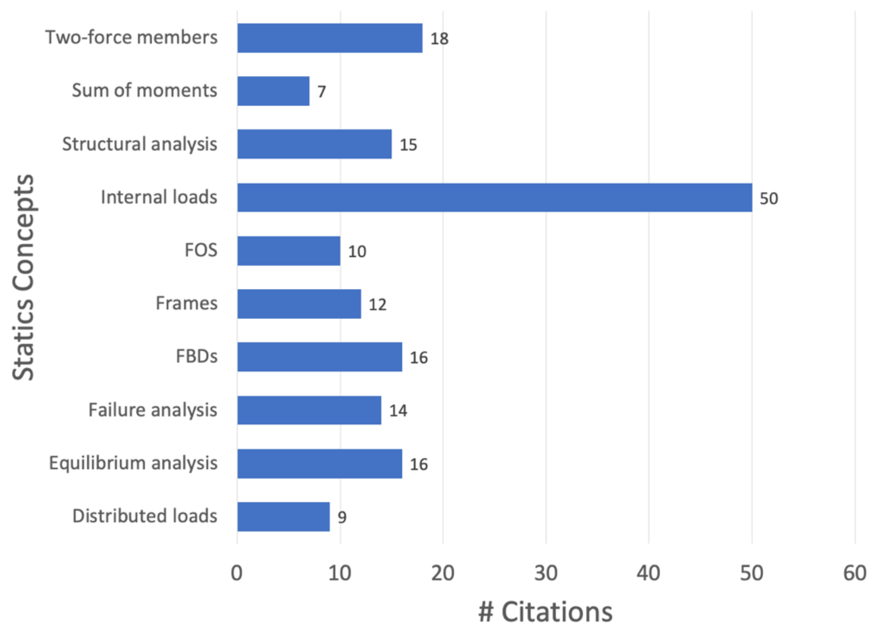

Figure 6. Statics concepts that were cited in free-response portion of the survey (*N*=110). FOS = Factor of Safety, FBD = Free Body Diagram

Table 4. Select student responses on end-of-term survey to the prompt: "Please feel free to provide any additional comments about the Wooden Bike Frame Project."

"Fun, but wish we had more time."
"This project was a great way to reinforce our understanding of certain statics concepts and posed interesting questions that kept people engaged."
"I really enjoyed this project and I think it showed me that being a mechanical engineer is fun. It was a breath of fresh air per say for me because after last semester I was feeling unsure about the major, but this project showed me what its all about and made me excited to become a junior and start the junior design project."
"I really enjoyed designing this bike and applying the knowledge gained from the course. This aspect is usually lost in classes and I am happy to have gotten this in this class."

Discussion

The paper presents a novel PBL experience for statics classes – the Wooden Bike Frame Challenge – that was specifically designed to give students real world experience with more challenging statics concepts. The learning objectives for this experience were twofold, namely, to improve understanding of structural analysis and to integrate statics concepts with prior knowledge of engineering design and prototyping. We demonstrated that the Wooden Bike Frame Challenge can be successfully embedded in a large-enrollment, lecture-based statics course. Several aspects of the PBL experience, including grade weighting, deliverables, and instructional scaffolds, were carefully designed to reinforce course learning objectives and fit the course's tight time and resource constraints.

The results of our study indicated that the Wooden Bike Frame Challenge improved student understanding of fundamental concepts in structural analysis, namely, two-force members, action-reaction pairs, and internal loads. Students demonstrated improved understanding of these concepts in the team PBL exercise and on structural analysis exam problems. Reflecting on the bike frame project, the majority of students perceived the experience improved their understanding of structural analysis and provided an opportunity to apply statics to real-world scenarios. Taken together, these results suggest that the Wooden Bike Frame Challenge improves student knowledge of advanced statics concepts, specifically structural analysis, and connects these concepts to real-world design scenarios.

While it is not the first statics based PBL exercise, the Wooden Bike Frame Challenge is a valuable addition to the engineering education literature. Prior studies have presented PBL exercises that have students construct: (1) suspension systems modeling 2D and 3D particle equilibrium scenarios [1, 21]; (2) single body two dimensional RBE systems [21]; and (3) "frames and machines" (structural analysis) such as bridges and truss systems [2-7]. The majority of prior studies involved development of scale models in lighter duty materials, such as bridges constructed from erector sets, balsawood, or straws [3, 4, 6]; and the argument could be made that this approach limits students' opportunities to design for and validate with the full-scale loading scenarios that they will be required to apply in actual practice. The Wooden Bike Frame Challenge is unique in this regard and requires students to consider full-scale loads (human body weight) and final materials (plywood and bolts) in engineering and validating the design. With the exception of Zhang [8], ours was one of few studies to examine whether a structures themed PBL exercise boosts student performance on textbook statics problems. Prior studies [1, 2, 5] have focused mainly on students' analytical and design self-efficacy. Our study adds to prior research by connecting the PBL experience to improved understanding of specific statics concepts like two-force members, action-reaction pairs, and internal loads.

There are several strengths and some limitations to our study. First, we used a robust, mixed-methods approach that allowed us to measure qualitative and quantitative changes in students' structural analysis skills. One limitation of the study is that we did not determine causality; in other words, we cannot definitively claim that the PBL design challenge directly led to the observed gains in students' ability to apply open-ended problem-solving skills in statics. While we have demonstrated correlation between PBL participation and student learning outcomes, causation could only be demonstrated through a randomized control or quasi-experimental study design. Nonetheless, we attempted to control confounding effects by narrowing the time window between pre- and post-PBL data collection to minimize the influence of additional learning about structural analysis or additional opportunities to develop engineering design skills. A final limitation of our study is that the structural analysis portion of the PBL exercise was carried out in a team-based setting, which does not ensure equal distribution of labor for all tasks. Approximately forty percent of students reported that they contributed less than their teammates or not at all to the structural analysis of their team's bike frame, which is the portion of the activity most closely aligned with course learning objectives. Despite this, approximately 90% of students perceived the PBL exercise reinforced their knowledge of structural analysis. This perception is, in part, supported by students' pre- to post-PBL performance on course exam problems, which indicated students were significantly more likely to correctly identify two-force members and apply action-reaction pairs. Students' abilities to correctly perform subcomponent rigid body equilibrium did not improve significantly by the end of the course.

The Wooden Bike Frame Challenge does require prerequisite coursework and prototyping resources that may not align with mechanical engineering programs at all institutions. Specifically, students need to have prior experience with CAD and familiarity with basic carpentry techniques. At our institution, we accomplish this with a second semester introductory mechanical engineering design course, which is taken in the term preceding Statics. Students also need access to basic carpentry equipment; and while not required, a large gantry CNC router expedites bulk manufacture of student designs. Prototyping costs for the design challenge were on the order of $5 per student in consumable materials (wood) and an additional $5 per student in reusable hardware (bolt assemblies).

In conclusion, this study introduced the Wooden Bike Frame Challenge, a course embedded PBL experience in which students apply structural analysis concepts to design a wooden bike frame. The Wooden Bike Frame Challenge is unique in that it involves design and validation of a full-scale structure using newly acquired statics knowledge in combination with prerequisite design skills. This PBL experience improved students' mastery of core structural analysis concepts, like two-force members, action-reaction pairs, and internal loads, and helped students connect statics concepts to real-world design.

Future work by our group will focus on modifying the Wooden Bike Frame Challenge to address student concerns about the compressed prototyping timeline and ensure that all students participate in the structural analysis portion of the exercise. It is the intention of our program to make the Wooden Bike Frame Challenge, which is now entering its sixth year, a permanent part of the curriculum in mechanical engineering. The PBL exercise and evaluative results presented in this study may be valuable for other programs looking to embed realistic, hands-on engineering design scenarios into core mechanics courses.

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