Developing Hands-on Physical Model Labs for Structures in Construction Courses

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Abstract

Construction mechanics and structures in construction courses are widely recognized as challenging subjects for construction engineering and management students. Funded by a grant from the Collier Building Industry Association and Collier Building Industry Foundation, this study explores the process of developing and implementing a hands-on physical model lab for a structures for construction course, aiming to improve student understanding of reinforced concrete concepts.

The development process began with analyzing Spring 2023 end-of-course feedback from two sections taught using traditional methods. Students expressed a strong desire for hands-on reinforced concrete labs. In response, we designed and implemented a new lab for Spring 2024, focusing on reinforced concrete beam models. This process involved careful selection of materials and building equipment from non-traditional sources.

The lab required students to assemble a reinforced concrete beam based on a given design. Students then engaged in collaborative discussions about the functions of various components (e.g., top and bottom bars, stirrups) and their placement, supporting their answers with annotated photos. Following the assembly and discussion, students disassembled the materials and created summary videos of their lab activities.

To assess the effectiveness of this new lab, we conducted a comparative analysis using 10 multiple-choice questions from Exam 3, consistent across both years. Questions 1-5 covered reinforced concrete structures (treatment), while questions 6-10 addressed wood structures (control). Results showed significant improvement in reinforced concrete scores for the instructor-consistent group from 2023 to 2024, with stable wood structure scores, suggesting the lab's effectiveness in enhancing learning specifically for reinforced concrete topics.

This study highlights the value of hands-on physical model labs in addressing persistent challenges in teaching complex structural concepts such as moment and shear force visualization, abstract calculations, and intricate mechanical principles. Moreover, it provides a replicable process for developing such labs, from initial student feedback to implementation and assessment. The findings underscore the potential for these labs to enrich construction engineering and management curricula, especially in advanced courses focusing on construction mechanics, structures, and systems.

Introduction

The challenge of teaching abstract concepts effectively has long been a central concern in higher education, particularly in technical fields where students must grasp complex theoretical principles and their practical applications [1]. Traditional lecture-based approaches, while efficient for content delivery, often struggle to bridge the gap between theory and practice. This disconnection is especially shown in construction engineering and management (CEM) education, where students must develop both theoretical understanding and practical competency in areas such as structural behavior, materials science, and construction systems [2], [3], [4].

Construction mechanics and structures courses present particular difficulties for CEM students, who must master intricate concepts like force distribution, moment calculations, and structural component interactions [5]. These challenges have shown in topics like reinforced concrete design, where students need to understand the complex interplay between multiple structural elements - from longitudinal reinforcement bars to stirrups - and their roles in resisting various forces [6]. Traditional teaching methods, primarily relying on two-dimensional drawings and theoretical calculations, often fall short in helping students visualize and comprehend these three-dimensional structural relationships, potentially leaving them underprepared for their future roles in the construction industry [7].

This study addresses these pedagogical challenges by documenting the development, implementation, and evaluation of a hands-on physical model lab focused on reinforced concrete beam construction. Through systematic development combining student feedback, careful material selection, and rigorous assessment, this research specifically targets the achievement of current Accreditation for Construction Education (ACCE) Student Learning Outcome 16 (ACCE SLO 16) (formerly ACCE SLO 19 prior to 2023), which requires students to "understand the basic principles of structural behavior" [8]. The findings offer valuable insights for CEM educators seeking to enhance student learning through experiential methods, while also providing a replicable framework for developing and accessing hands-on laboratories in CEM education.

Literature Review

The effectiveness of hands-on learning in CEM education has been well-documented across numerous studies. Research has consistently shown that physical models and laboratory experiences enhance student understanding of complex engineering concepts [9], [10], [11]. For example, the ExCEEd (Excellence in Civil Engineering Education) Teaching Workshop, which has trained nearly 1,000 faculty members more than two decades, emphasizes that physical models and demonstrations are crucial for helping students visualize complex concepts and bridge the gap between theory and practice [12]. The benefits of hands-on learning extend beyond CEM education, as demonstrated in a meta-analysis by Yammine and Violato [13], which found that physical models in anatomy education significantly improved overall knowledge acquisition and spatial knowledge retention compared to traditional lecture-based methods. This reinforces the cognitive advantages of tangible learning tools, which are similarly valuable in CEM education. Similarly, Self and Widmann [14] found that both hands-on and instructor-led demonstrations of mechanical engineering principles led to significantly higher student performance compared to traditional lecture-based instruction, with students in interactive learning environments scoring up to 25% higher than those taught using passive methods. In nursing education, LoVerde et al. [15] demonstrated that students who engaged in manipulative-based learning approaches exhibited significantly greater intention to apply knowledge to real-world practice compared to those who only received lecture-based instruction. Likewise, Khalid [16] found that flight simulation as a hands-on learning tool in aviation training significantly improved student knowledge retention and problem-solving abilities, underscoring the long-term benefits of interactive education in technical disciplines, including CEM.

Despite the growing emphasis on practical learning, CEM programs often lack structured approaches to incorporating hands-on laboratories into their curricula [17]. Studies have noted that the alignment between course objectives, hands-on activities, and assessment strategies is frequently ad hoc rather than systematic [18]. Moreover, there is a scarcity of resources detailing how institutions can effectively plan and implement such laboratories within budgetary constraints and logistical challenges [19]. Addressing these issues requires a cohesive framework that integrates pedagogical objectives with practical considerations, including space, equipment, and faculty expertise.

Another area of concern highlighted in the literature is the difficulty in systematically assessing the impact of hands-on learning. While studies frequently report improved engagement and conceptual understanding, there is limited consensus on the metrics and methodologies that should be used to evaluate these outcomes [20]. As Austin and Rust [21] note, while developing student learning outcomes may not be difficult, determining how to measure them and developing consistent rubrics across different types of experiential activities requires extensive discussion and training. The lack of standardized assessment frameworks complicates comparisons across studies and hampers efforts to establish best practices in CEM education.

While extensive research exists on pedagogical techniques in higher education, significant gaps remain in developing systematic, evidence-based approaches for teaching abstract concepts in structural engineering education. Current literature lacks comprehensive frameworks that guide institutions through the entire process of developing and implementing hands-on laboratories - from initial needs assessment through implementation and assessment. This study addresses these gaps by providing both a systematic framework for laboratory development and a rigorous methodology for assessing learning outcomes across multiple dimensions.

Methodology

The study employed a mixed-methods approach to develop and evaluate the effectiveness of a hands-on physical model lab for teaching reinforced concrete concepts in a structures for construction course. The research focused on junior-year undergraduate students majoring in a construction management program at a public university in Florida, representing a critical point in their academic progression when they begin engaging with advanced structural concepts. As shown in Figure 1, the research methodology unfolded across three distinct phases: (1) needs assessment, (2) lab development and implementation, and (3) effectiveness evaluation.

The initial needs assessment phase, conducted in Spring 2023, began with an end-of-semester survey integrated into the standard student perception of instruction (SPoI) evaluation. The survey specifically targeted construction management juniors' perceptions regarding potential learning enhancements aimed at improving their achievement of the ACCE SLO 16 "Understand the basic principles of structural behavior." Students were asked to evaluate various proposed additions to the curriculum, indicating their level of agreement about whether each addition would enhance their learning experience.

Building on these findings, the second phase focused on developing and implementing a comprehensive reinforced concrete beam lab for Spring 2024. The development process involved careful consideration of material selection, equipment procurement, and instructional design tailored to the undergraduate construction management curriculum. The lab was structured to engage students in practical assembly of reinforced concrete beams based on provided design specifications. Beyond mere construction, the lab incorporated collaborative discussion components where students analyzed the functions of various structural elements, including top and bottom bars and stirrups. Students documented their work through annotated photographs and created summary videos of their lab activities. These documentation activities enhanced both their technical understanding and communication skills.

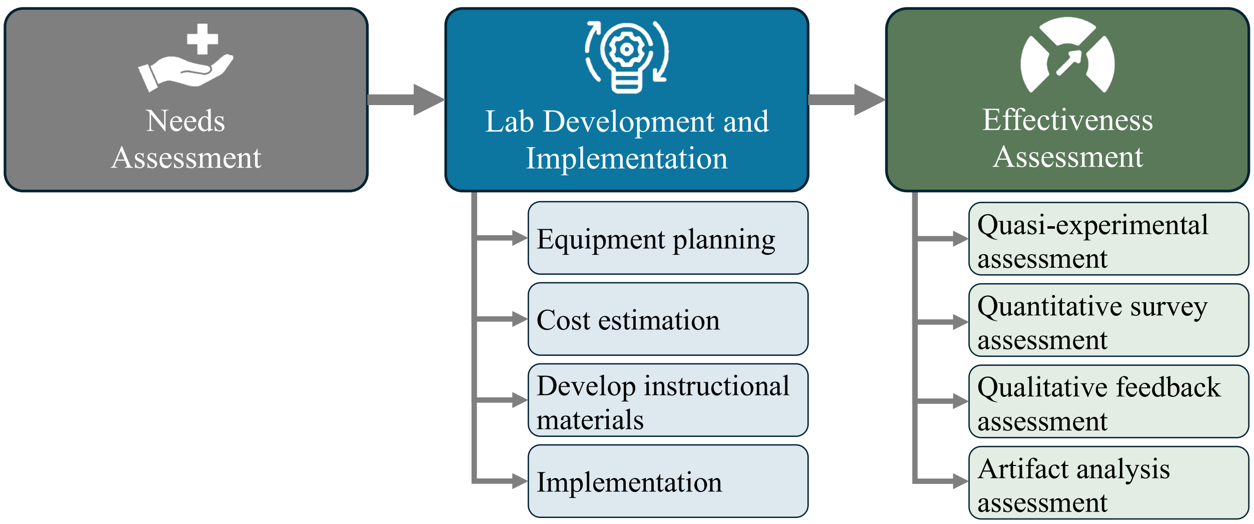

Figure 1. Research methodology flowchart

To evaluate the effectiveness of this new lab implementation, the study utilized a quasi-experimental design comparing student performance across two academic years (2023 and 2024) and two course sections of junior-level construction management students. The evaluation focused on student performance in the multiple-choice question part of Exam 3, which contained ten multiple-choice questions divided into two parts: questions 1-5 covering reinforced concrete structures (the treatment group) and questions 6-10 addressing wood structures (serving as a control group). Details of the 10 multiple-choice questions part from Exam 3 are available upon request. This design allowed for both within-group and between-group comparisons, with Session 1 maintaining instructor consistency across both years while Session 2 experienced an instructor change. Student feedback was collected through both quantitative surveys and qualitative open-ended questions to provide a comprehensive understanding of the lab's impact on student learning and engagement. Additionally, student lab reports and summary videos were also collected and reviewed as supplementary evidence of learning outcomes.

Results and Discussion

Needs Assessment

Figure 2 presents the results of a student survey conducted at the end of Spring 2023. Students were asked to respond to the following question: "This class has been used to assess the Student Learning Outcome 'Understand the basic principles of structural behavior' required by the American Council for Construction Education (ACCE). Indicate the extent to which you agree or disagree that the following additions would enhance your learning." With a response rate of 42/52 (80.8%), the survey evaluated student responses across 6 different potential additions to the course, including various lab activities, with responses ranging from "Strongly Disagree" to "Strongly Agree" on a five-point Likert scale.

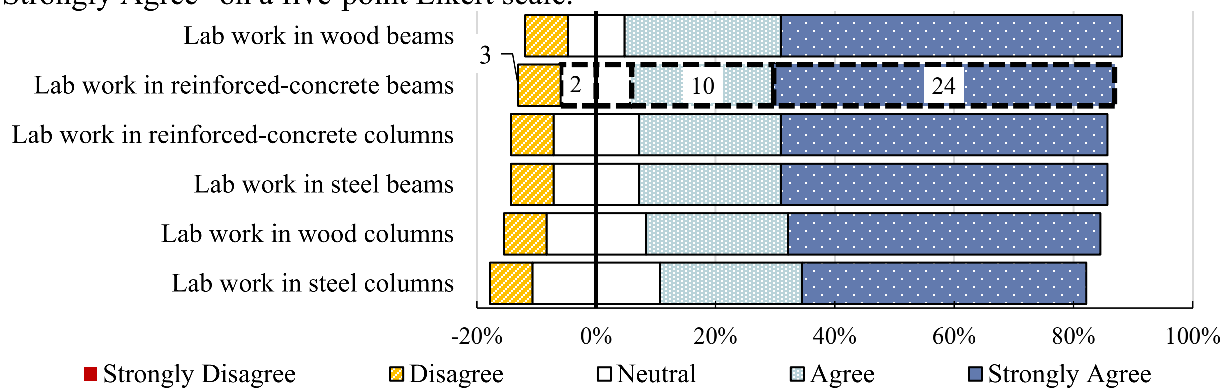

Figure 2. Student preferences for course content enhancement in structures for construction course (Spring 2023, N = 42)

The survey results revealed strong student support for hands-on laboratory work, particularly in reinforced-concrete topics. Specifically for lab work in reinforced-concrete beams, 24 students (57.1%) strongly agreed, and 10 students (23.8%) agreed that it would enhance their learning experience, making it one of the most positively received potential additions to the curriculum. The findings provided strong support for developing and implementing this hands-on learning experience in the subsequent academic year.

Lab Development and Implementation

Building on the student support for hands-on laboratory work identified in the needs assessment phase, we developed a comprehensive reinforced concrete beam lab focusing on practical assembly and theoretical understanding. The lab development process began with careful selection of materials and equipment that would be both cost-effective and suitable for educational purposes. As shown in Table 1 and Figure 3, we procured various materials and equipment, including rebar tie guns, wire twisters, and different sizes of reinforcement bars. The total investment in materials and equipment totaled approximately $940.85 (as shown in Table 1) to serve a class of 40 students, averaging about $24 per student. This relatively modest cost-to-student ratio makes the lab implementation financially feasible for other institutions to replicate, especially considering that most materials like rebar tie guns and wire twisters can be reused across multiple semesters.

Table 1. Materials and equipment quantities and unit costs (as of November 2023)

Materials and Equipment	Unit	Unit cost	Quantity	Cost
Rebar tie gun 1	Each	$139.89	1	$139.89
Rebar tie gun 2	Each	$306.90	1	$306.90
Wire twister	Each	$4.22	10	$42.20
Double loop rebar wire ties	Roll	$9.90	2	$19.80
#3 stirrup 9" x 21"	Each	$1.91	120	$229.20
#4 bars 1'-6'-1'	Each	$3.04	22	$66.88
#5 straight bars 2' long	Each	$1.20	12	$14.40
#5 straight bars 3' long	Each	$1.80	12	$21.60
#6 straight bars 3' long	Each	$2.61	12	$31.32
#5 12"x12" 90^0 bars	Each	$1.20	12	$14.40
Rebar chairs	Each	$0.36	15	$5.40
Rebar paints	Each	$6.98	7	$48.86
Total				$940.85

Figure 3. Key laboratory equipment and materials: (a) #3 stirrup 9" x 21", (b) rebar tie gun 1, (c) rebar tie gun 2, (d) sawhorse, (e) #5 straight bars 2' long, (f) double loop rebar wire ties, (g) rebar wire tie coil, (h) wire twister, (i) #5 straight bars 3' long, (j) rebar chairs, (k) rebar paints, (l) #5 12"x12" 90^0 bars, (m) #6 straight bars 3' long, (n) wire cutter, (o) #4 bars 1'-6'-1'

The next step was developing instructional materials for the lab. Details of the lab instruction can be found in Appendix below. We created a detailed construction drawing (Figure 4) that students would use as their primary reference for assembling reinforced concrete beams. To optimize the learning experience within laboratory constraints, we intentionally scaled down the beam's dimensions by a factor of five horizontally from typical construction specifications. This scaling resulted in a 72-inch continuous beam, which, while unusually short by industry standards, provided two key advantages: it allowed students to complete the assembly within the 75-minute lab period and accommodated multiple student groups in the limited laboratory space. Despite this modification, we maintained realistic proportions in the cross-sections (15" x 24") and authentic structural detailing across three distinct sections (K1, K2, and K3). Each section featured industry-standard stirrup spacing requirements: 4-inch on-center spacing at the beam ends (K1 and K3) and 6-inch spacing in the middle section (K2). All rebars and stirrups were painted with distinct colors that help students easily identify different components, protect students from potential rust exposure, and preserve the materials for reuse across multiple semesters. While scaled for educational purposes, these specifications preserved the key structural relationships students would encounter in full-scale construction projects.

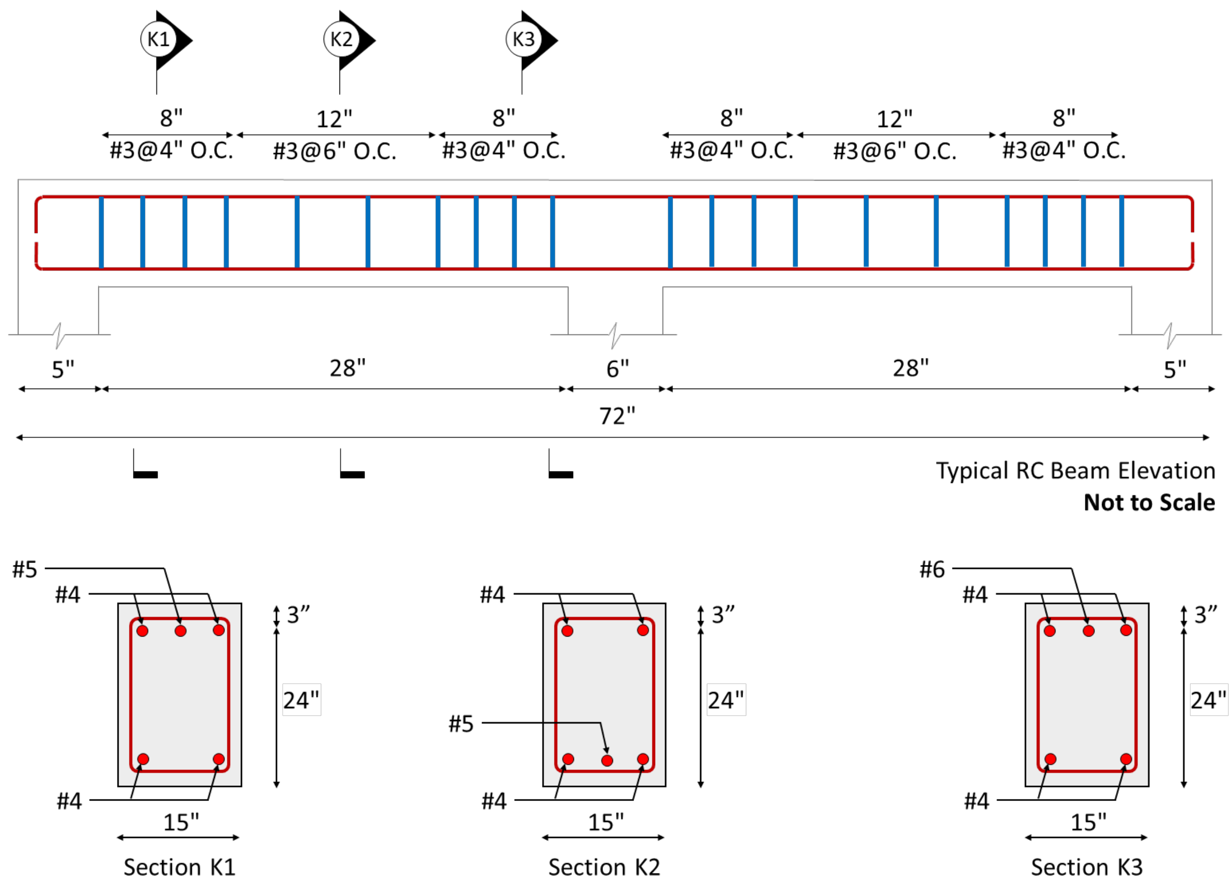

Figure 4. Reinforced concrete beam design drawing

Figure 5 shows students working in lab activities. Students are required to wear personal protective equipment (PPE), including hard hats, long paints, safety vests, and safety shoes during the activities. Although protective gloves were provided, some students opted to remove them during intricate tying tasks to improve tactile sensitivity for handling small wire ties and reinforcement components. This hands-on activity allowed students to better understand the spatial relationships between stirrups and longitudinal bars that are often limited to 2D drawings.

Working in coordinated groups, they developed technical skills, collaborative problem-solving abilities, and a deeper understanding of construction standards and management practices.

Figure 5. Students participating in reinforced concrete beam lab

Effectiveness Evaluation

The quasi-experimental assessment served as the primary measurement for evaluating the lab's effectiveness through a carefully designed comparative analysis. Using a controlled study design, we examined exam performance between Spring 2023 and Spring 2024 across two course sections. As shown in Figure 6, the analysis focused on two parts of Exam 3 where Part 1 covering reinforced concrete concepts (treatment) and Part 2 covering wood structures (control). The error bars represent the standard errors. Each section was taught by different instructors, with Session 1 maintaining the same instructor across both years while Session 2 experienced an instructor change. A two-sample t-test was used to compare the mean scores between the two cohorts and to evaluate whether the observed differences were statistically significant.

In Session 1, where instructor consistency was maintained, the implementation of the hands-on lab was associated with a statistically significant improvement in Part 1 scores (t = -2.35, df = 62, p-value = 0.022). Students in 2024 demonstrated higher performance (Mean = 8.10) compared to their 2023 counterparts (Mean = 6.40). The corresponding effect size (Cohen’s d = 0.461) indicates a moderate effect, supporting the conclusion that the hands-on lab had a positive impact on student understanding of reinforced concrete concepts. Importantly, Part 2 scores, which covered untreated topics, showed no significant change between 2023 (Mean = 8.80) and 2024 (Mean = 9.38) (t = -1.75, df = 62, p-value = 0.085). This pattern suggests that the improvement in Part 1 scores can be reasonably attributed to the implementation of the hands-on lab rather than general cohort differences or other course-wide enhancements.

In Session 2, which experienced an instructor change, significant improvements were observed in both Part 1 (t = -7.08, df = 61, p-value < 0.001) and Part 2 (t = -18.99, df = 61, p-value < 0.001). The improvements in Part 1 scores (Mean = 3.52 in 2023 to Mean = 7.68 in 2024) correspond to a large effect size (Cohen’s d = 1.477), indicating a strong impact on reinforced concrete concepts. Similarly, Part 2 scores (Mean = 4.08 in 2023 to Mean = 9.58 in 2024) demonstrated an extremely large effect size (Cohen’s d = 3.959), suggesting that instructor-related factors likely played a more dominant role in this section's performance changes than the specific impact of the lab implementation.

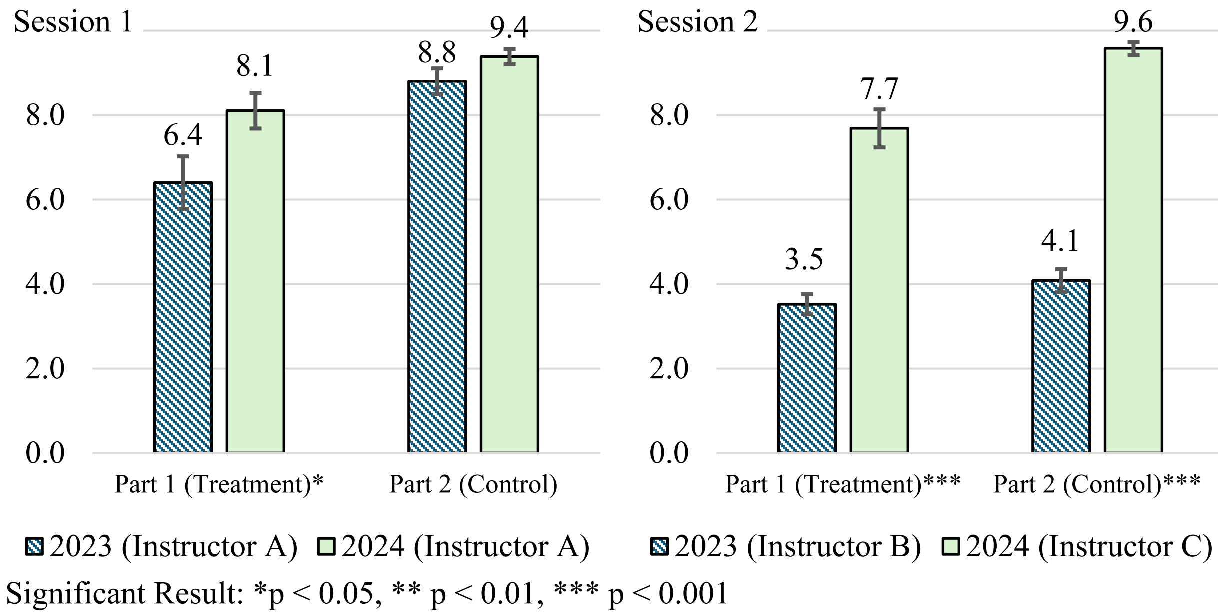

Figure 6. Comparison of mean exam grades between 2023 and 2024 for reinforced concrete (part 1) and wood structures (part 2) topics

In addition to the quasi-experimental assessment, we also do the quantitative survey assessment. Students were asked to indicate their level of agreement with seven statements about the reinforced concrete beam lab, ranging from "Strongly Disagree" to "Strongly Agree." Analysis of their feedback revealed overwhelmingly positive responses across multiple dimensions of the learning experience (Figure 7). The strongest positive response was observed in the areas of teamwork/communication and real-world relevance, with approximately 97% and 94% of students respectively either agreeing or strongly agreeing with these aspects. The lab's alignment with learning outcomes also received notable approval, with 94% of students expressing agreement or strong agreement that the objectives effectively supported their understanding of structural behavior principles. While most aspects of the lab were very well-received, the duration of lab sessions emerged as a relative concern, with 21% of students expressing disagreement or strong disagreement about the adequacy of time allocated. Despite this timing concern, students largely felt confident in their reinforced concrete skills post-lab, with 77% indicating agreement or strong agreement with increased confidence levels.

Students also were asked to evaluate how different learning activities contributed to their understanding of theoretical concepts in the reinforced concrete beam lab (Figure 8). The hands-on activities of placing longitudinal bars and stirrups emerged as the most highly valued activities, with approximately 97% of students respectively agreeing or strongly agreeing about their effectiveness in understanding theoretical concepts. Discussion with teammates also received strong positive feedback, with 95% positive responses. While most activities were well-received, the use of automatic rebar tie guns showed relatively lower satisfaction, with 84% positive responses but also the highest level of disagreement (6.5%) among all activities. This lower rating can be attributed to the limited availability of equipment, as only two rebar tie guns were available for all student groups to share. This suggests a clear area for future improvement - increasing the number of automatic rebar tie guns to ensure better access and hands-on experience for all students.

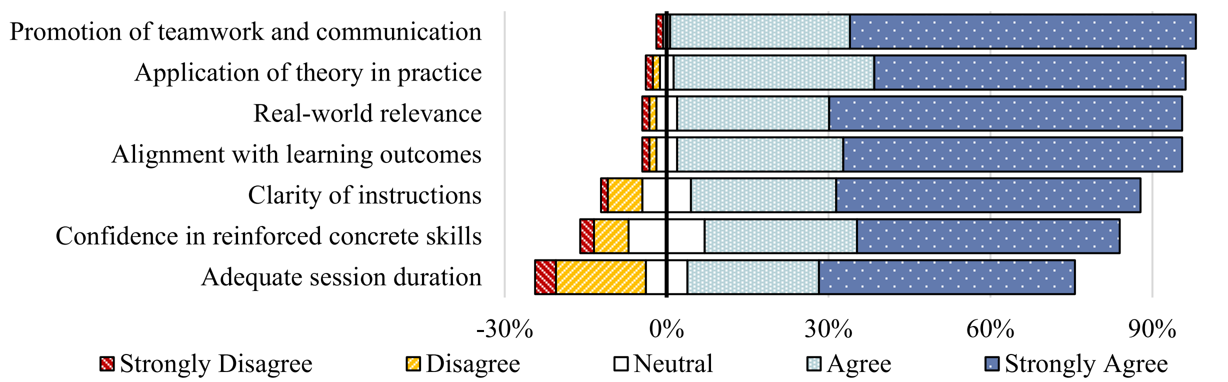

Figure 7. Student perceptions of lab implementation aspects (N = 79)

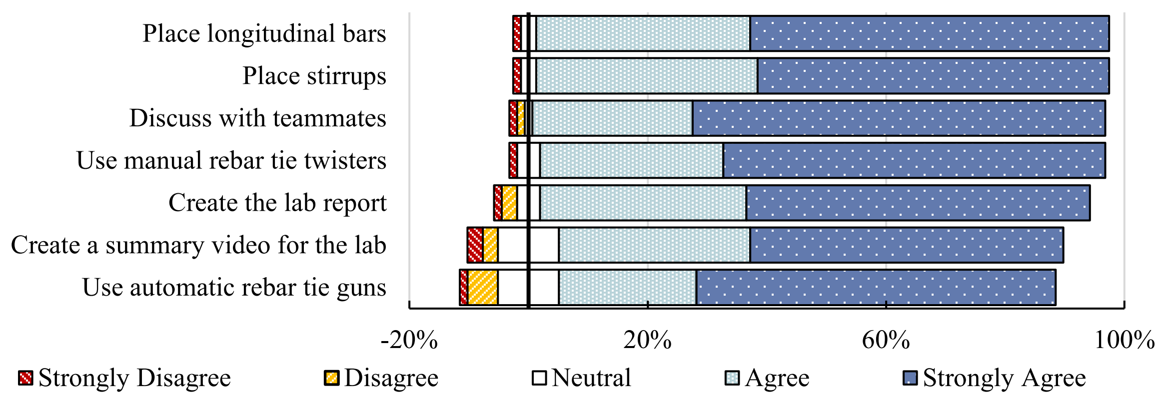

Figure 8. Student perceptions of learning activities in the reinforced concrete beam lab (N = 79)

For the qualitative feedback assessment, students were asked two open-ended questions about their experience with the reinforced concrete beam lab:

a) What did you like most about the reinforced concrete beam lab?
b) What improvements would you suggest for future reinforced concrete beam labs?

The responses were analyzed using thematic analysis, with results presented in Figure 9a and Figure 9b below. When asked about the most valued aspects of the lab (Figure 9a), the dominant theme was Hands-on Learning Experience, representing 45% of responses. Students particularly valued the direct interaction with materials, as shown by one response: "*Getting to place the rebar ourselves instead of just watching someone else do it. You really get to see why and how things are placed in the real world.*" Enhanced Understanding and Teamwork and Collaboration each accounted for 15% of responses, with one student noting that "*it really helped me understand the theoretical and apply it into practice*," while another emphasized that "*collaborating with classmates to set up experiments, analyze data, and draw conclusions added a dynamic element to the lab experience*." Real-World Application (10%) and Engagement and

Enjoyment (9%) emerged as additional benefits, with students appreciating both the practical relevance ("*we used real world materials and learned how to work as if we were in the field*") and engaging nature of the experience ("*I enjoyed doing it, it was fun to build*").

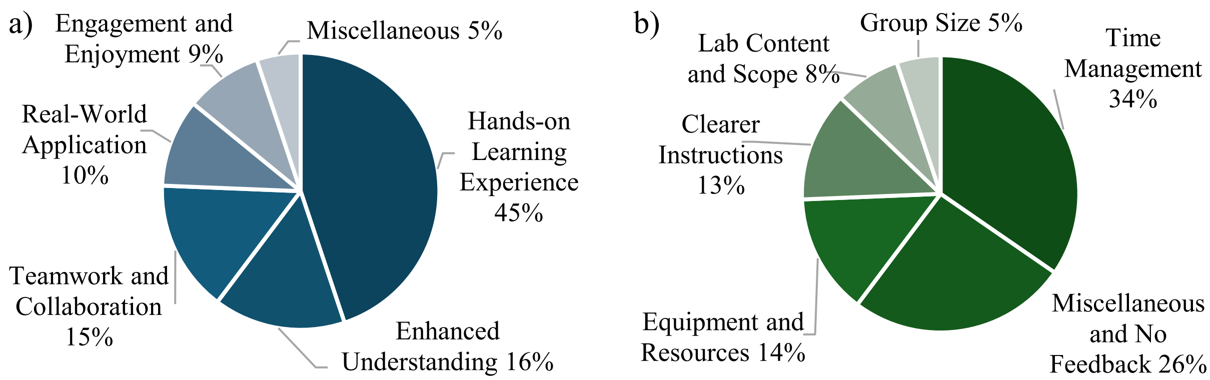

Figure 9. Student qualitative feedback on reinforced concrete beam lab: a) most valued aspects and b) suggested improvements

Regarding suggestions for improvement, Time Management emerged as the primary concern, with 35% of responses indicating a need for longer duration. As one student explained, they needed "*more time to complete the lab, so that we can actually get the experience without rushing through it*." Equipment and Resources was the second most common theme (14%), with students requesting additional tools: "*Have more equipment like tables and steel tie guns... some groups couldn't finish their lab due to having to wait for other groups*." Clearer Instructions represented 13% of responses, with students requesting "*better figures to follow, clearer instructions for those of us who have never done something like that before*." Lab Content and Scope (8%) and Group Size (5%) were also identified as areas for improvement, with suggestions to "*actually use concrete*" and create "*smaller groups so everyone is more involved*" respectively. A notable portion of responses (26%) indicate satisfaction or no specific suggestions for improvement.

Finally, the artifact analysis assessment involves evaluating student reports and summary videos to determine lab grades. Evaluation of student laboratory reports and summary videos revealed strong comprehension of reinforced concrete concepts and thorough documentation of the hands-on experience. The mean score for laboratory reports was 9.6 out of 10 points, demonstrating exceptional understanding of the required technical concepts. Minor point deductions were primarily related to incomplete documentation of Personal Protective Equipment (PPE) requirements rather than conceptual misunderstandings. The quality of student summary videos demonstrated clear understanding of the laboratory content. Students effectively explained key concepts like stirrup placement and reinforcement configurations while showing the assembly process. Many submissions featured insightful explanations overlaid with demonstrations of construction techniques. Figure 10 presents an example of a student-submitted video, accessible via the public YouTube link below.

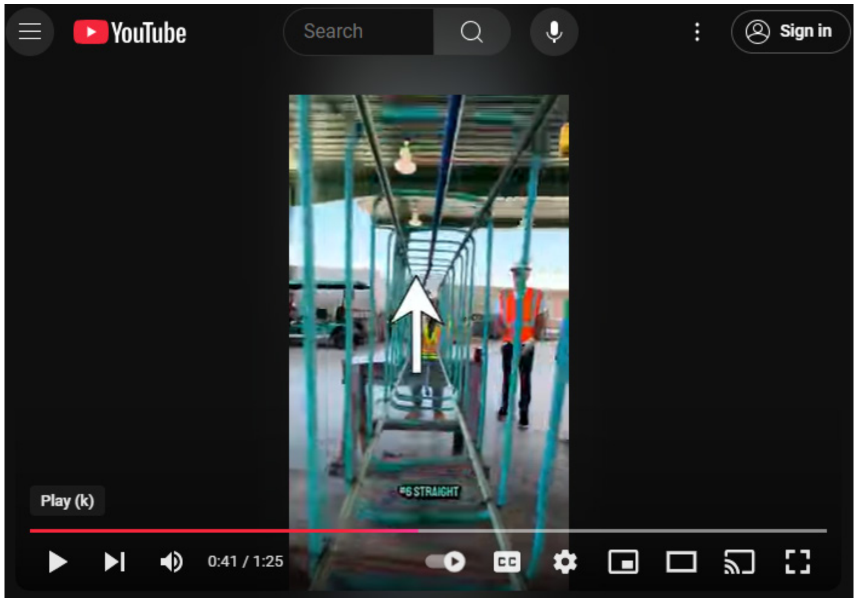

Figure 10. Example of student-submitted video (https://youtu.be/eHuNEQSdOLE) [22]

Conclusions and Recommendations

This study demonstrates that hands-on laboratory experiences can be effectively implemented in CEM education with relatively modest investment. The reinforced concrete beam laboratory proved to be a financially viable addition to the curriculum, particularly considering the reusability of key equipment. The quasi-experimental assessment revealed statistically significant improvements in student performance on reinforced concrete topics in the instructor-consistent group, while performance on control topics remained stable, suggesting the lab's strong impact on learning outcomes. These results align with the Accreditation for Construction Education (ACCE) Student Learning Outcome 16 (formerly SLO 19), which requires students to 'understand the basic principles of structural behavior' [8]. Additionally, this hands-on approach supports key ABET Criterion 3 Student Outcomes by fostering problem-solving abilities (Outcome 1), teamwork (Outcome 5), and application of engineering principles (Outcome 2) [23]. Student feedback was overwhelmingly positive, with over 90% reporting enhanced learning through teamwork and practical application, further reinforcing the effectiveness of hands-on learning in achieving accreditation-based educational objectives.

However, several limitations were identified during implementation. The initial implementation faced resource constraints, particularly regarding the availability and capacity of rebar tying guns. In response to this challenge, we recently invested in two additional professional-grade MAX USA RB398S rebar tying guns (shown in Figure 11), each costing approximately $2,500. While this represents a significant investment, institutions with available funding may find that allocating resources to additional tying guns significantly enhances the lab experience by allowing more hands-on practice for each student. Time management emerged as another significant challenge, with 34% of students indicating that the 75-minute session duration was insufficient for completing all lab activities. These constraints could be addressed by either extending the lab to two sessions or reducing the introductory component to allow more hands-on time.

Future research should explore several promising directions. First, investigating the long-term retention of structural concepts through longitudinal studies could provide valuable insights into the lasting impact of hands-on laboratories. Second, examining the potential for incorporating virtual reality or augmented reality technologies could enhance the visualization of full-scale structures while maintaining the benefits of physical manipulation. Finally, developing a standardized assessment framework for measuring the effectiveness of hands-on laboratories across different CEM programs could facilitate broader adoption and continuous improvement of these teaching methods.

Figure 11. Rebar tying gun

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Reference

[1] J. C. Hayes and D. J. M. Kraemer, “Grounded understanding of abstract concepts: The case of STEM learning,” *Cognitive Research: Principles and Implications*, vol. 2, no. 1, p. 7, Jan. 2017, doi: 10.1186/s41235-016-0046-z.

[2] S. Persaud and M. Smit, “A 21st century approach to teaching engineering mechanics,” in *International Conference on Engineering and Product Design Education*, Oslo, Norway, 2017, pp. 704–709.
[3] A. C. Aparicio and A. M. Ruiz-Teran, “Tradition and innovation in teaching structural design in civil engineering,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 133, no. 4, pp. 340–349, Oct. 2007, doi: 10.1061/(ASCE)1052-3928(2007)133:4(340).
[4] E. Reyes and J. C. Gálvez, “Introduction of innovations into the traditional teaching of construction and building materials,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 137, no. 1, pp. 28–37, Jan. 2011, doi: 10.1061/(ASCE)EI.1943-5541.0000033.
[5] J. B. Guthrie, “Engineering for architecture and construction management students: teaching methods and changing needs,” presented at the 2012 ASEE Annual Conference & Exposition, San Antonio, Texas, Jun. 2012, p. 25.1181.1-25.1181.13. doi: https://doi.org/10.18260/1-2--21938.
[6] N. Rumsey, J. Russell, and K. Tarhini, “Innovative approach to teaching undergraduate reinforced concrete design,” in *2010 IEEE Frontiers in Education Conference (FIE)*, Oct. 2010, pp. T1C-1-T1C-5. doi: 10.1109/FIE.2010.5673651.
[7] S. Glick, D. Porter, and C. Smith, “Student visualization: using 3-d models in undergraduate construction management education,” *International Journal of Construction Education and Research*, vol. 8, no. 1, pp. 26–46, Jan. 2012, doi: 10.1080/15578771.2011.619247.
[8] American Council for Construction Education (ACCE), “Document 103: Standards and criteria for the accreditation of construction education programs,” 2024. [Online]. Available: https://www.acce-hq.org/file-share/
[9] A. C. Estes, R. W. Welch, and S. J. Ressler, “The ExCEEd teaching model,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 131, no. 4, pp. 218–222, Oct. 2005, doi: 10.1061/(ASCE)1052-3928(2005)131:4(218).
[10] J. S. Shiau, S. Pather, and R. Ayers, “Developing physical models for geotechnical teaching and research,” in *Physical Modelling in Geotechnics - 6th ICPMG ’06*, C. W. W. Ng, L. M. Zhang, and Y. H. Wang, Eds., Hong Kong, Jan. 2006, pp. 157–162. Accessed: Dec. 01, 2024. [Online]. Available: http://www.amazon.com/Physical-Modelling-Geotechnics-ICPMG062-CDROM/dp/0415415861
[11] K. F. Meyer, S. J. Ressler, and T. Lenox, “Visualizing structural behavior: using physical models in structural engineering education,” presented at the 1996 ASEE Annual Conference & Exposition, Jun. 1996, p. 1.524.1-1.524.8. Accessed: Dec. 01, 2024. [Online]. Available: https://peer.asee.org/visualizing-structural-behavior-using-physical-models-in-structural-engineering-education
[12] A. C. Estes *et al.*, “Celebrating 20 years of the ExCEEd teaching workshop,” presented at the 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah, Jun. 2018. doi: https://doi.org/10.18260/1-2--30180.
[13] K. Yammine and C. Violato, “The effectiveness of physical models in teaching anatomy: a meta-analysis of comparative studies,” *Adv in Health Sci Educ*, vol. 21, no. 4, pp. 883–895, Oct. 2016, doi: 10.1007/s10459-015-9644-7.
[14] B. Self and J. Widmann, “Demo or hands-on? A crossover study on the most effective implementation strategy for inquir--based learning activities,” in *2017 ASEE Annual*

Conference & Exposition, Columbus, Ohio: ASEE Conferences, Jun. 2017, p. 28101. doi: 10.18260/1-2--28101.
[15] J. A. LoVerde, C. Kerber, T. Kisch, B. Miller, S. Jenkins, and M. Shropshire, "Comparison of lecture and manipulative teaching methods on learning and application to practice," *Nursing Forum*, vol. 56, no. 3, pp. 520–528, 2021, doi: 10.1111/nuf.12575.
[16] A. Khalid, "Flight simulation based case study to compare student learning, performance and retention," *JHETP*, vol. 21, no. 1, Mar. 2021, doi: https://doi.org/10.33423/jhetp.v21i1.4043.
[17] P. W. Plugge, "A hands-on concrete laboratory framework for construction management education," presented at the 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland, Jun. 2023. doi: https://doi.org/10.18260/1-2--42404.
[18] S. Nightingale, A. Carew, and J. B. Fung, "Application of constructive alignment principles to engineering education: Have we really changed?," in *Proceedings of the 2007 AaeE Conference*, Melbourne, Australia, 2007.
[19] N. Woolcock, "Universities put building work on hold and cut staff in cash crisis." Accessed: Dec. 19, 2024. [Online]. Available: https://www.thetimes.com/uk/education/article/universities-put-building-work-on-hold-and-cut-staff-in-cash-crisis-9c3flnc96
[20] S. Radović, H. G. K. Hummel, and M. Vermeulen, "The challenge of designing 'more' experiential learning in higher education programs in the field of teacher education: a systematic review study," *International Journal of Lifelong Education*, vol. 40, no. 5–6, pp. 545–560, Nov. 2021, doi: 10.1080/02601370.2021.1994664.
[21] M. J. Austin and D. Z. Rust, "Developing an experiential learning program: milestones and challenges," *International Journal of Teaching and Learning in Higher Education*, vol. 27, no. 1, pp. 143–153, 2015.
[22] Myah Ramirez *et al.*, "Lab summary for structures in construction spring 2024," Structures for Construction, 2024. [Online]. Available: https://youtu.be/eHuNEQSdOLE
[23] Accreditation Board for Engineering and Technology (ABET), "Criteria for accrediting engineering programs, 2024 – 2025," 2024. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2024-2025/

Appendix: Lab Instruction

Objectives:
The goal of this lab is to apply theoretical knowledge of continuous beams, including aspects of negative and positive moments, shear forces, and the use of top bars, bottom bars, and stirrups, in a practical setting.

General Requirement
For this lab, you are required to make two submissions:

- Submission 1: Lab report (please refer to the template on Canvas)
- Submission 2: Lab summary video.

Safety Required:
All participants must wear the following safety gear:

- Hard hat
- Safety vest
- Construction gloves
- Long pants
- Safety glasses
- Safety shoes

Note: Please submit one photo showing all team members with proper PPE wear to receive full credit for the lab report.

Material and Equipment:
You are given the following tools to complete the lab:

- #3 stirrup 9" x 21"
- #5 straight bars 2' long
- #5 straight bars 3' long
- #5 12"x12" 90^0 bars
- #6 straight bars 3' long
- #4 bars 1'-6'-1'
- rebar tie gun 1
- rebar tie gun 2
- sawhorse
- double loop rebar wire ties
- rebar wire tie coil
- wire twister
- rebar chairs
- rebar paints
- wire cutter

Part 1: Rebar Placement

- Refer to provided shop drawing and select the suitable materials and equipment to construct the beam.

- Check *Canvas* → *People* → *Concrete Lab Group* to identify your team members. Collaboration within your group is essential for this activity.
- It's required for students to record videos of the assembly process, which will later be used to create a summary video.
- Based on the drawing provided, decide on the rebars necessary for the construction.
- Upon completing the lab, take a minimum of 4 photos from various angles to document your work. Ensure at least one photo includes all team members wearing Personal Protective Equipment (PPE) alongside the finished rebar beam.
- Notes: The beam's dimensions are scaled down by a factor of five horizontally to facilitate easier handling and tying of the stirrups, resulting in an unusually short beam and short splicing lengths.

Part 2: Quantitative Take Off

Please record the amount of each type of material and each piece of equipment utilized.

Material	Quantity
…	…
…	…

Part 3: Discussion

Please collaborate with your team to discuss and provide answers to the questions below:

1. What is the function of top bar #5 on Section K1 and top bar #6 on Section K3?
2. What is the function of bottom bar #5 on section K2?
3. What is the function of bars #4 on section K2? Make sure to fully address all functions of those bars.
4. What are the functions of the stirrups #3?
5. Why do we use stirrup #3@2"O.C. on Section K1 and Section K3 and use stirrups #3@4"O.C. on Section K2?
6. Discuss the use of top bar #6 in Section K3 and bottom bar #5 in Section K2. Why is a smaller bar used in Section K2?

Please answer the questions using photos that show what we're talking about. For each answer, add at least one photo with arrows pointing to where the rebar is. You can use PowerPoint to draw arrows to highlight the specified components. For example:

Answer	Photos
The function of top bars is to support…	
…	…

Part 4: Disassembly

Please cut the rebar wire ties using wire cutters and take apart your setup. Then, take a photo as proof that show your team have fully disassembled the rebars.

Part 5: Create Summary Videos

Please create a video summarizing your lab activities using any social media or video creation tool (such as YouTube Shorts, Instagram Reels, OBS, etc.). Ensure your video does not exceed 2 minutes in length. Submit the URL link of your video.

Bonus (+3 points): Enhance your video with a narrative that includes at least one answer from Part 2 discussion questions. For instance, you might say, “Today, we worked on reinforcing a concrete beam in the lab, focusing on the placement of rebars. Here’s rebar number 6 on the top of the beam. Its main purpose is [Insert your answer here]. The square bars are called stirrups, and here we're using stirrup #3...” Get creative with your video presentation!