Establishing the Structural Learning Lab: Enhancing Engagement and Understanding in Civil Engineering Education

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1. Introduction

The *Structural Learning Lab* at California State University, Sacramento (CSUS) was established to address educational gaps in civil engineering curricula, particularly the challenges students face in visualizing and comprehending abstract engineering concepts. The initiative, supported by the 2025 Probationary Faculty Development Grant, has transformed a previously underutilized storage area into a dynamic, interactive educational space. This report summarizes the project's objectives, methodologies, outcomes, and future directions.

2. Project Context and Objectives

2.1 Background

Rooms 1001A and 1001B within the Structural Lab at California State University, Sacramento (CSUS) have been used to store a variety of physical models and other resources intended to support instruction in civil engineering courses. However, prior to this project, these spaces faced several limitations, including disorganization, outdated instructional manuals, the absence of an inventory tracking system, and underutilized teaching resources. These issues made the materials difficult to access and limited their effectiveness as instructional tools for both faculty and students. In many cases, instructors were unaware of the available models or how to incorporate them meaningfully into their courses, reducing opportunities for active, hands-on learning.

To address these challenges, this project reorganized the spaces, focusing primarily on Room 1001A, which was designated as the dedicated *Structural Learning Lab*. The effort included implementing a structured inventory and check-out system and updating or creating instructional manuals to support the effective use of the models. In addition, the project introduced new interactive physical models designed to help students better visualize and understand key structural engineering concepts, such as load paths, deflections, and stress states, that are often difficult to grasp through traditional lecture-based instruction. The effectiveness of these interventions is being evaluated through student surveys, focus groups, and comparative analyses of course performance data.

The broader aim of the project is to establish the *Structural Learning Lab* as a dynamic, inclusive, and pedagogically effective learning environment that enhances both teaching and learning outcomes. Beyond improving comprehension and engagement, the initiative seeks to address equity gaps in engineering education by making hands-on, visual learning tools more accessible to women, first-generation college students, and individuals from historically underrepresented groups in STEM.

2.2 Objectives

The Structural Learning Lab project was designed with the following key objectives:

- Reorganize and optimize existing educational resources.
- Update instructional manuals and guidelines.
- Develop innovative physical models to facilitate hands-on learning.
- Evaluate the lab's impact on student comprehension and engagement.
- Reduce equity gaps among underrepresented student populations.
- Disseminate the lab's capabilities to faculty in the civil and mechanical engineering departments.
- Present project outcomes at the American Society for Engineering Education (ASEE) Conference.

2.3 Literature Review

Recent research emphasizes the value of incorporating physical and visual models into engineering education to support student learning, engagement, and spatial reasoning. Chen et al. (2011) showed that tangible and augmented reality models can improve students' ability to interpret three-dimensional structures and spatial relationships. In a similar study, Behrouzi et al. (2023) found that physical tools in reinforced concrete courses helped students understand complex topics such as the equivalent rectangular stress block, leading to stronger comprehension and retention.

Virtual reality (VR) and immersive 3D technologies have also been used to support engineering instruction. Sampaio et al. (2010) explored the application of VR in construction education, while Fogarty et al. (2018) demonstrated its effectiveness in helping students visualize structural behaviors such as buckling. However, the widespread use of these technologies is often limited by cost, time, and integration challenges, particularly in undergraduate settings.

Physical models, by contrast, continue to offer a practical, low-cost alternative with strong pedagogical benefits. Addis et al. (2020) emphasized their enduring role in both education and engineering practice. Kadlowec et al. (2002) highlighted the success of hands-on tools like instrumented beams in teaching fundamental mechanics concepts. Yildirim et al. (2017) also reported improved student understanding of prefabrication processes using balsa wood models, though that study did not focus on structural design concepts such as load paths or sequencing.

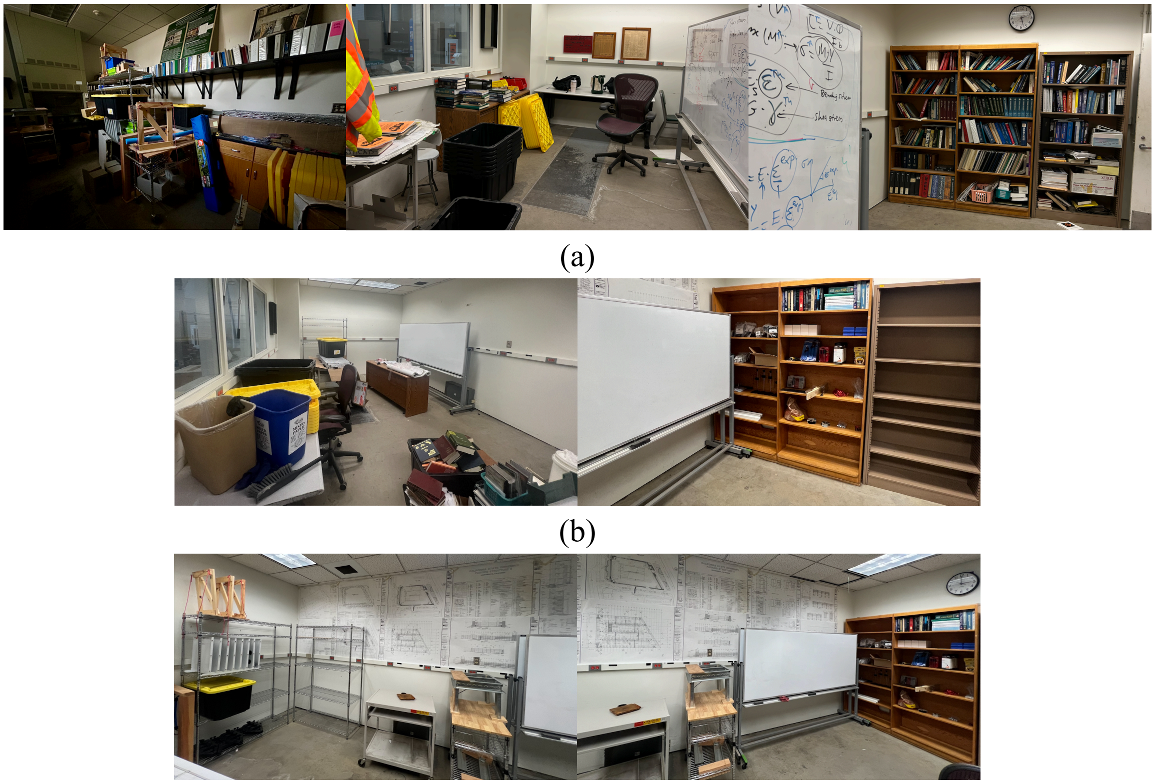
This project responds to a specific need in civil engineering education, the limited availability of modular physical models designed to support the teaching of structural behavior. The newly developed Load Path Explorer, Flex Frame, and Stress Cube were created to help students visualize and interact with core structural concepts that are often difficult to understand through traditional lecture materials alone. Accompanied by updated instructional manuals and guided classroom activities, these models provide a practical and inclusive way to strengthen student learning in structural engineering courses.

3. Methodology

Based on my teaching experiences in ENGR112 (Mechanics of Materials) and CE160 (Intro to Structural Analysis), I identified significant challenges faced by students, especially those with visual learning preferences, in grasping fundamental engineering principles such as load paths and stress states. Supported by the mentorship and prior initiatives of Dr. Fogarty and Dr. Garcia, this project established the *Structural Learning Lab* to reorganize existing resources, update instructional materials, and introduce innovative physical models. Throughout this project, rigorous assessment strategies were implemented to evaluate improvements in student comprehension and faculty satisfaction.

Task 1: Resource Reorganization

A comprehensive digital inventory system was developed and implemented, categorizing and clearly labeling existing educational resources according to instructional relevance. The storage area was reorganized into a structured and accessible learning environment featuring dedicated demonstration areas to encourage student interaction with educational models. The inventory management system utilized a *Google Form-based tracking mechanism*, enabling efficient monitoring of item condition and check-in/check-out status. Each item was assigned a unique identifier (ID) following a standardized naming format, which combined details of item type, room, shelf, and row locations. Real-time updates on item conditions and availability were automated using formulas integrated into a linked *Excel spreadsheet*, ensuring accurate and up-to-date records. Figure 1 provides photographs comparing the storage room before, during, and after reorganization.



(a)

(b)

(c)

Figure 1. Progressive reorganization of the space: (a) initial state of the room and disorganized and unused materials; (b) intermediate phase showing partial clearing and rearrangement; and (c) final organized layout.

Task 2: Manual Updates

The educational manuals, designed to guide users through the assembly, setup, and classroom use of the physical models, were revised and shared with students during the Spring 2025 semester. As part of an optional project activity in the CE166 (Seismic Behavior of Structures) elective, senior-level students used the physical models to demonstrate and explain two structural engineering concepts of their choice. This hands-on engagement not only reinforced their understanding but also generated valuable feedback. Based on their input, the manuals were further refined to include clearer instructions and practical classroom examples. Formal peer review by faculty is planned for Fall 2025 to ensure pedagogical rigor and technical accuracy across all instructional materials.

Task 3: Development of New Physical Models

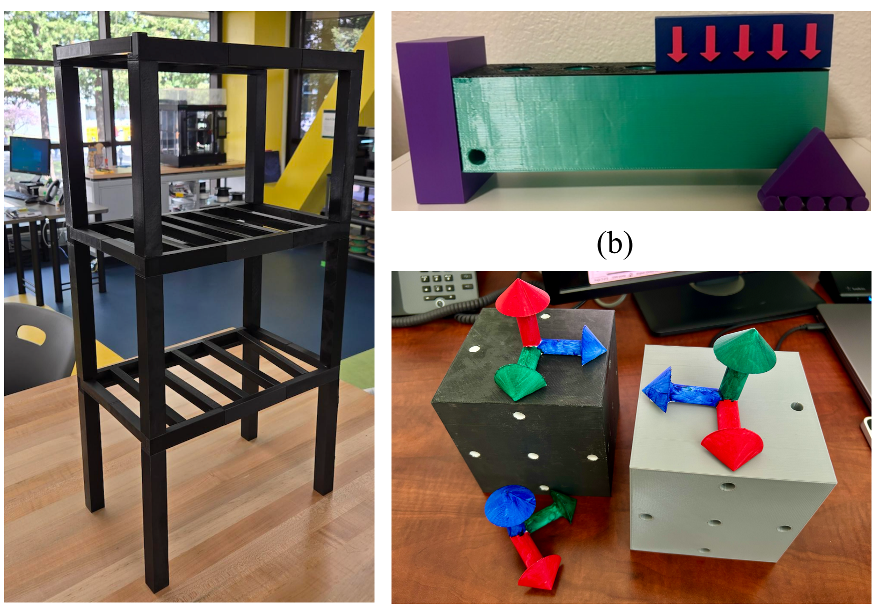
Three innovative physical models, including the Load Path Explorer, the Flex Frame, and the Stress Cube, were developed to enhance students' understanding of key structural engineering concepts through hands-on interaction.

Load Path Explorer: This modular, scaled building model was designed in SolidWorks and fabricated using a Bambu Lab FDM 3D printer with PLA filament. It allows students to visualize load distribution, tributary areas, and structural design sequences interactively. The modularity enables students to assemble one- to three-story structures, encouraging spatial reasoning and system-level thinking.

Flex Frame: Currently under development, this model demonstrates deflection and deformation of beams and frames under various load and support conditions. It is constructed from flexible, rubber-like materials using resin-based 3D printing. The frame includes interchangeable members with varying stiffness and supports (fixed, roller, pinned), enabling real-time observation of structural response.

Stress Cube: Designed as a tangible aid for visualizing stress states at a material point, the Stress Cube was fabricated using rigid PLA material and features color-coded faces for clarity. It is equipped with magnetic arrows that can be positioned to represent normal and shear stresses. This model helps students understand the concept of stress tensors, sign conventions, and 3D stress orientations. concepts that are often abstract and difficult to grasp in traditional lectures.

All three models were designed to be accessible, durable, and adaptable for classroom use. Their integration into instruction is supported by educational manuals guiding users on assembly, setup, and instructional applications. Figure 2 shows the three developed physical models.



(b)

(a) (c)

Figure 2. Developed physical models: (a) Load Path Explorer; (b) Flex Frame; and (c) Stress Cube.

During the Spring 2025 semester, the physical models were piloted in multiple courses, including CE160 (Structural Analysis) and CE166 (Seismic Behavior of Structures). In CE160, a hands-on demo activity using the Load Path Explorer was conducted with both course sections. As shown in Figure 3, this activity allowed students to interact directly with a scaled structural model to deepen their understanding of key concepts. The primary learning objectives were to visualize how loads transfer from slabs through beams, girders, and columns down to the foundation; to explore tributary loading in both one-way and two-way systems; and to comprehend the sequencing of structural design and construction that governs how loads move through a building. This tactile learning experience helped bridge the gap between theoretical diagrams and real-world behavior, enhancing student engagement and comprehension.

Figure 3. CE160 students participating in a hands-on demo activity using the Load Path Explorer Model.

Task 4: Evaluation and Engagement

A mixed-methods evaluation approach was developed to assess the effectiveness and impact of the *Structural Learning Lab* and the implemented physical models. The primary evaluation during Spring 2025 focused on the Load Path Explorer through a hands-on demo activity in CE160. Pre-implementation and Post-implementation surveys were administered to students to measure their conceptual understanding, spatial reasoning, and engagement before and after the activity. This allowed for a direct assessment of the model's instructional value in a classroom setting.

In Fall 2024, a prototype version of the Stress Cube was introduced in ENGR 112. However, due to the early-stage nature of the model at the time, a more formal evaluation of the finalized Stress Cube will be conducted in Fall 2025, when I will be teaching ENGR 112 again and can directly integrate the model into the course for structured assessment. Similarly, although a preliminary version of the Flex Frame was introduced in CE160 during Spring 2025, the final version, currently being printed, will be evaluated during a demo session in the future.

Future Tasks

Looking ahead, dissemination and faculty engagement are planned to expand the impact of the *Structural Learning Lab*. Faculty in the civil and mechanical engineering departments will be invited to explore the physical models and instructional manuals now available in the lab. Their feedback will support continued refinement of the models and promote broader integration of these resources into the curriculum. Surveys will be administered to both students and faculty before and after using the models to assess changes in conceptual understanding, instructional effectiveness, and overall satisfaction. In parallel, student performance data, such as grade distributions in CE160, will be tracked over time, allowing for comparison between Spring 2025 and future semesters to evaluate the long-term impact of the lab on student learning outcomes.

4. Results

This section focuses primarily on the implementation and initial impact of the Load Path Explorer model, which was piloted during the Spring 2025 semester in CE160. While other models, such as the Stress Cube and Flex Frame, were introduced in prototype form, their finalized versions will be implemented and assessed in future semesters. These evaluations are planned for Fall 2025, when the models will be integrated into ENGR 112 and CE160 using similar demo activities and pre/post surveys to measure their effectiveness. Additionally, a more comprehensive evaluation of the *Structural Learning Lab* as a whole, including its influence on teaching practices, student engagement, and equitable access to hands-on learning tools, will be carried out over time. Faculty feedback, student focus groups, and longitudinal comparisons of grade distribution data (e.g., CE160 Spring 2025 vs. future offerings) will support these efforts. The findings presented here provide a foundation for these future assessments and reflect the early outcomes of the lab's integration into the civil engineering curriculum.

To assess students' baseline understanding before the implementation of the Load Path Explorer, a survey was administered to approximately 50 students enrolled in CE160 during Spring 2025. The survey evaluated both conceptual knowledge and self-reported confidence in topics related to structural load paths and design sequences. As shown in Figure 4a, while a strong majority of students (85%) correctly defined a load path, substantial gaps appeared in applied understanding. Only 56% correctly identified load transfer in a one-way slab, 49% classified systems as one-way or two-way, and just about 40% accurately understood construction versus design sequencing or identified the largest tributary area in a given floor plan.

Student confidence ratings followed a similar trend. As shown in Figure 4b, students reported the highest confidence when explaining load transfer sequences (mean = 3.25), but lower confidence when identifying tributary areas (3.04), classifying structural systems (2.91), and describing the sequencing of construction and design (2.84). These results suggest that while students grasp foundational terminology, many struggle with spatial reasoning and system-level decision-making, highlighting the need for interactive, visual tools that can bridge the gap between theoretical concepts and applied understanding.

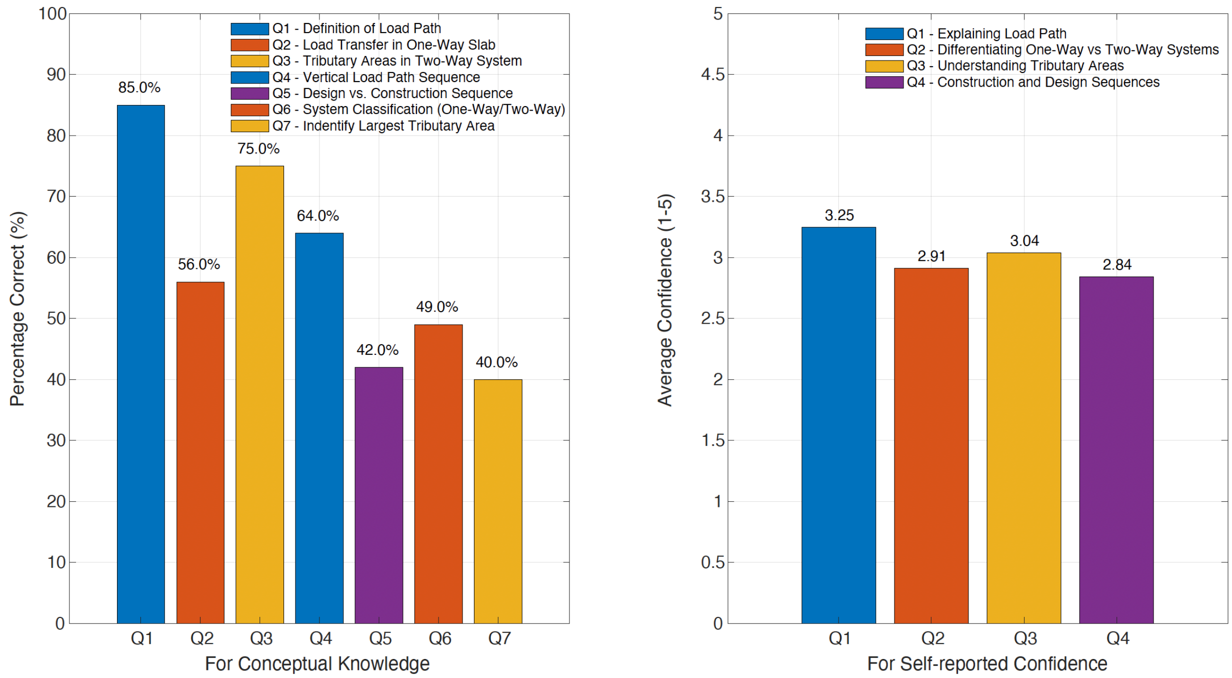


Figure 4. Results from the pre-implementation survey for the *Load Path Explorer* model: (a) Percentage of correct responses to conceptual knowledge questions, and (b) Mean of student self-confidence ratings for structural reasoning concepts. Confidence ratings: 1 = Not confident, 5 = Very confident. Color coding is consistent across both parts of the figure to represent shared conceptual topics.

The Load Path Explorer was developed to address the conceptual and spatial reasoning gaps identified in the baseline survey. After participating in a hands-on demo, where students assembled the modular model to trace load transfer from slabs to foundations, they completed a post-implementation survey designed to mirror the initial assessment.

The results shown in Figure 5 indicate a clear improvement in students' self-reported confidence across all structural reasoning concepts. Confidence in explaining load paths increased from 3.25 to 3.92; differentiating one-way versus two-way systems rose from 2.91 to 4.12; understanding tributary areas improved from 3.04 to 3.98; and confidence in construction versus design sequencing increased from 2.84 to 3.90. These findings suggest that the Load Path Explorer enhanced students' confidence by facilitating visual and physical engagement with structural concepts and their interrelationships within a complete system.

The results from the conceptual knowledge questions were more mixed. Students demonstrated improvement in several areas, for example, understanding the vertical load path sequence increased from 64% to 82%, and correct classification of structural systems rose from 49% to 68%. However, accuracy in identifying the largest tributary area remained unchanged at 40%, while performance declined in questions related to design versus construction sequencing and load transfer in one-way slabs. These findings suggest that, although students gained confidence, certain theoretical concepts remain unclear.

One possible explanation is that students may have interpreted the model assembly process, which begins at the foundation and builds upward, as reflective of the structural design sequence. While this bottom-up logic aligns with construction practices, structural design typically follows a top-down approach, beginning with elements that initially receive loads (such as slabs or roof systems) and continuing downward through the load path. This confusion may have contributed to difficulty in distinguishing between design and construction logic. To address this, future iterations of the activity should include clearer instructional scaffolding to emphasize the top-down nature of structural design and help students make this distinction more explicitly.

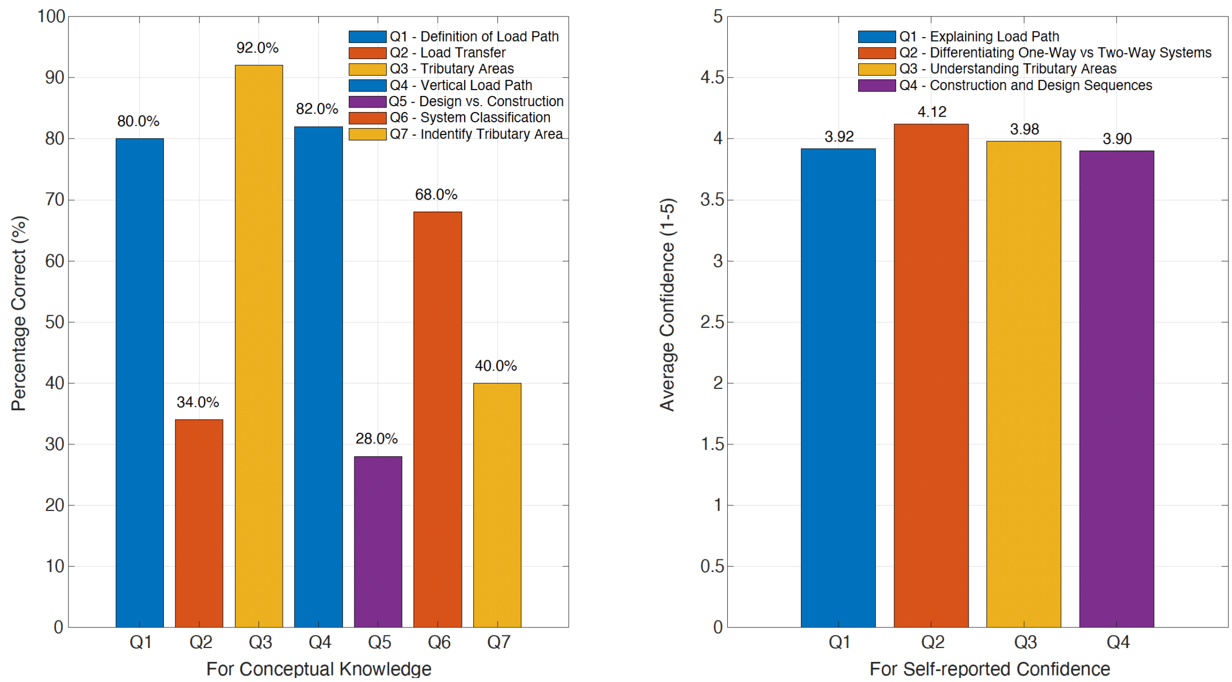


Figure 5. Results from the post-implementation survey for the *Load Path Explorer* model: (a) Percentage of correct responses to conceptual knowledge questions, and (b) Mean of student self-confidence ratings for structural reasoning concepts. Confidence ratings: 1 = Not confident, 5 = Very confident.
Color coding is consistent across both parts of the figure to represent shared conceptual topics.

Overall, these findings underscore the potential of the Load Path Explorer to enhance both student confidence and conceptual understanding in structural engineering. They also point to opportunities for refining instructional strategies, especially for abstract or process-oriented topics such as the distinction between construction and design sequencing. In addition to measuring gains in knowledge and confidence, the post-survey also included two sections aimed at capturing student perceptions and qualitative feedback on the model itself.

First, students evaluated the model based on three attributes: ease of interaction, realism in representation, and usefulness in connecting theoretical concepts to physical systems. Ratings were consistently positive, with average scores exceeding 4.40 across all categories. These results reinforce the model's effectiveness as an instructional tool. Second, students provided open-ended feedback. Many praised the model's flexibility, visual clarity, and usefulness in helping them understand how loads transfer through a structure. Comments included: "very helpful visually to understand each part of the structure," "easy to replace and remove beams," and "helpful to see in real-world concepts we learned in class." Students also valued the collaborative nature of the activity and noted that the model made abstract structural ideas feel more concrete and accessible.

Students also provided constructive feedback to guide future improvements to both the physical model and its instructional implementation. Some recommended incorporating additional visual aids or expanding the model with varied loading components, such as different types of point loads or column configurations. Others suggested reducing group size or allowing more time for students to engage with the model prior to formal instruction. This feedback will support ongoing refinement of the activity and its supporting materials, with particular emphasis on strengthening explanations of tributary loading and reinforcing the distinction between structural design and construction sequences.

Collectively, this feedback reflects strong student engagement and a desire for continued use of hands-on tools in engineering education. It also offers practical direction for enhancing the *Structural Learning Lab's* resources.

5. Dissemination

Preliminary findings from the Load Path Explorer implementation were presented at the 2025 American Society for Engineering Education (ASEE) Annual Conference & Exposition and will be published in the corresponding proceedings. The presentation highlighted key outcomes related to student confidence, conceptual understanding, and the role of physical models in enhancing structural engineering education.

Further dissemination efforts are planned as the *Structural Learning Lab* continues to expand. These include sharing implementation strategies, instructional materials, and model design files with faculty in the civil and mechanical engineering departments at California State University, Sacramento. Faculty feedback and collaboration will be essential in refining the models and integrating them into additional courses. Long-term, the project aims to contribute to broader conversations on inclusive and hands-on engineering education through future conference presentations, workshops, and peer-reviewed publications.

6. Impact on Diversity and Inclusion

The *Structural Learning Lab* directly supports CSUS's commitment to diversity and inclusion by offering tangible educational resources that accommodate a range of learning styles and backgrounds, particularly benefiting traditionally underserved student populations. The enhanced visualization and hands-on experiences provided by the models are designed to mitigate documented disparities in spatial reasoning skills among women, first-generation students, and students from historically underrepresented racial and ethnic groups.

Demographic data collected during the Load Path Explorer hands-on demo in Spring 2025 further underscore the relevance of this approach. Among the approximately 50 participants, 61% identified as male and 35% as female, highlighting the continued importance of promoting gender diversity in engineering. Additionally, 47% of students identified as Hispanic or Latino, 24% as Asian or Asian American, and over 41% reported being first-generation college students. This diversity reinforces the critical role of accessible, interactive teaching tools in addressing equity gaps and fostering engagement across a broad student population.

7. Future Work and Recommendations

Future work will focus on conducting comprehensive evaluations of the other physical models developed through the *Structural Learning Lab*, including the Stress Cube and Flex Frame, as they are formally implemented in upcoming course offerings. These assessments will follow the same structured approach used for the Load Path Explorer, incorporating both quantitative and qualitative measures to evaluate their educational impact. In parallel, efforts to expand faculty engagement will continue through targeted workshops and demonstrations, encouraging broader adoption of the models across the curriculum. Ongoing user feedback from both students and faculty will guide future iterations of the models and the development of new instructional materials, ensuring continued improvement and innovation aligned with evolving pedagogical needs.

8. Conclusion

The *Structural Learning Lab* represents a significant step toward enhancing civil engineering education at California State University, Sacramento. By transforming an underutilized space into an interactive learning environment, the project has addressed long-standing challenges related to student engagement and comprehension of abstract engineering concepts. Through the development of hands-on physical models, such as the Load Path Explorer, Flex Frame, and Stress Cube, students are now able to visualize load paths, structural deflections, and stress states in ways that complement and enrich traditional lecture-based instruction.

Initial findings from the implementation of the Load Path Explorer demonstrate meaningful improvements in students' confidence and applied understanding of structural systems. Positive feedback from students, along with thoughtful suggestions for improvement, confirms the value of physical, visual learning tools in promoting deeper engagement and comprehension. Moreover, the demographic data collected during this pilot activity affirms the lab's inclusive design: by serving a diverse student population, the *Structural Learning Lab* will reduce equity gaps and support the success of women, first-generation students, and historically underrepresented groups in engineering.

Looking forward, the continued evaluation of additional models and expansion of faculty engagement will ensure that the lab remains a dynamic and evolving resource. As more students and instructors integrate these tools into their coursework, the *Structural Learning Lab* is poised to become a cornerstone of active, inclusive, and effective engineering education at CSUS.

9. References

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