Establishing the ’Structural Learning Lab’: A Hands-On Approach to Enhancing Engagement and Understanding in Civil Engineering Education (WIP)

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Abstract

This Work-in-Progress (WIP) report outlines the development of the *Structural Learning Lab*, an interactive learning center designed to enhance student engagement and improve comprehension of complex civil engineering concepts. The project focuses on reorganizing existing resources and integrating new physical models, including the *Load Path Explorer* and the *Flex Frame*, to provide students with tangible, hands-on representations of theoretical content. These models will be incorporated into civil engineering courses to deepen understanding of key topics such as load paths, construction sequences, and structural deflections.

The lab addresses a critical need in civil engineering education: providing practical tools that enhance students' spatial visualization skills. Many students struggle with abstract concepts when taught solely through traditional lecture-based methods. By offering interactive physical models, the lab bridges the gap between theory and real-world application. In addition to improving student learning, the lab will serve as a resource for faculty, supporting the integration of active learning tools into instructional practices.

Research indicates that hands-on learning tools are especially effective for students from underrepresented groups, including women and minorities, who often face additional challenges in courses requiring strong spatial reasoning skills. The Structural Learning Lab's focus on tangible learning aids aims to reduce these barriers and contribute to higher retention and success rates among diverse student populations.

This WIP report presents the initial steps in establishing the lab, including the design and construction of new models, the reorganization of existing materials, and early insights from pilot implementations. It also provides a preliminary analysis of students' initial understanding of structural load paths and related concepts before introducing the *Load Path Explorer* educational tool.

Expected outcomes include improved student comprehension of structural principles, increased engagement in active learning environments, and greater faculty use of hands-on teaching resources. Impact will be assessed using a mixed-methods approach, including pre- and post-implementation surveys, focus groups, and analysis of grade distribution reports, providing both quantitative and qualitative measures of effectiveness. Improved student retention may also emerge as a longer-term benefit.

Introduction

Engineering education increasingly demands innovative approaches to meet the diverse needs of students, particularly in mastering complex theoretical concepts. The *Structural Learning Lab* was conceived to provide hands-on learning experiences through physical models, responding to documented challenges in spatial visualization and engagement within traditional lecture-based environments. By integrating interactive tools, the lab bridges the gap between theory and real-world applications, fostering deeper comprehension and student engagement.

The lab specifically addresses challenges in civil engineering education by offering practical tools that enhance spatial reasoning, improve active learning, and support faculty instructional practices. The primary objectives of this Work-in-Progress are to improve students' understanding of structural principles through tangible learning aids, increase engagement through hands-on experiences, address equity gaps for underrepresented groups, and assist faculty in integrating innovative teaching resources into the curriculum.

Background

The Structural Lab currently houses physical educational models and materials used for engineering education, but faces several challenges, including disorganization, a lack of inventory, outdated guidelines, and unused resources. These issues make the lab inaccessible and ineffective for both faculty and students. Without an organized system, faculty often remain unaware of available materials or how to incorporate them effectively into their teaching, which in turn limits students' opportunities for hands-on learning.

Reorganizing and cataloging the lab's resources will improve accessibility, clarify available teaching tools, and support better curriculum integration. This project also involves updating outdated manuals and introducing new, interactive physical models to strengthen students' understanding of fundamental engineering concepts. The impact of these updates will be assessed through surveys, focus groups, and grade distribution analyses.

The primary goal is to establish the *Structural Learning Lab* as a dynamic, effective learning center that enhances both teaching and student engagement. The project aims to answer how the lab's establishment influences faculty use of teaching resources, student understanding of complex concepts, and engagement in civil engineering courses. Additionally, it will explore whether more accessible, hands-on experiences can help close equity gaps for women and underrepresented minority students across multiple engineering courses.

Literature Review: Enhancing Learning Through Physical and Virtual Models

The integration of tangible models in engineering education has been shown to significantly enhance student comprehension and engagement. Chen et al. [1] demonstrated how tangible and augmented reality models improve students' spatial understanding and ability to interpret three-dimensional structures. Similarly, Behrouzi et al. [2] found that tangible tools in reinforced concrete design helped students grasp complex concepts like the equivalent rectangular stress block, improving comprehension and retention.

Virtual reality (VR) and 3D modeling technologies also offer immersive experiences that enhance understanding, as shown by Sampaio et al. [3] and Fogarty et al. [4]. Sampaio highlighted VR's use in developing construction education materials, while Fogarty focused on VR's role in clarifying complex structural behaviors, such as buckling. However, high costs and significant integration time often limit VR's broader adoption in educational settings [5].

Due to these barriers, physical models remain a relevant, cost-effective alternative. Addis [6] emphasized their lasting role in both instruction and professional practice, providing hands-on understanding of complex engineering concepts. Further evidence by Kadlowec et al. [7] shows the effectiveness of models like instrumented beams for teaching forces, moments, and stresses. Yildirim et al. [8] also demonstrated how a balsa wood model improved students' understanding of prefabrication concepts, though their study did not address load paths or design sequences critical in structural engineering.

By integrating new physical models such as the *Load Path Explorer* and *Flex Frame*, this project aims to enhance learning through hands-on experiences and to address the current gap in modular physical models for teaching load paths, deflections, and design processes. Developing clear guidelines for these models further advances engineering education by making complex topics more tangible and accessible.

Methodology and Expected Outcomes

The project methodology involves four key tasks:

Reorganization of Resources

The first task focuses on establishing the lab's functionality and accessibility. A comprehensive inventory of physical models and materials is being conducted to catalog and label resources effectively. The lab space is reorganized to align materials with specific courses and instructional topics, and a dedicated area for hands-on demonstrations is being created to encourage student interaction. The expected outcome of this task is a streamlined, accessible lab environment that enhances teaching effectiveness and enriches learning experiences.

Updating Manuals

The second task involves updating the educational manuals associated with the lab's resources. Manuals are being reviewed and revised to ensure technical accuracy, relevance to modern engineering practices, and alignment with real-world applications. Faculty members are invited to contribute their expertise, and the revised manuals undergo peer review to ensure pedagogical reliability. The expected outcome is a user-friendly set of instructional resources that promotes faculty adoption and supports active learning.

Development and Integration of Physical Models

As part of the third task, two educational physical models are being developed to enhance students' structural understanding through hands-on learning: the *Load Path Explorer*, which is fully developed, and the *Flex Frame*, which is under construction. Both models are designed to reinforce core engineering concepts such as load paths, spatial visualization, internal forces, and structural stability.

Load Path Explorer: Description and Fabrication Process

The *Load Path Explorer* is a scaled physical model specifically created to illustrate fundamental structural engineering concepts, including load paths, one-way versus two-way systems, and the sequence of design and construction. The model allows students to interactively assemble building structures of up to three stories using modular components that represent key structural elements such as joists, beams, girders, and columns. Through this hands-on assembly, students are able to visualize how loads are transferred through the structure, bridging the gap between abstract 2D representations and three-dimensional real-world systems.

The model was designed using SolidWorks CAD software to reflect realistic structural relationships and typical construction sequences. A 1:25 scale was selected to preserve spatial accuracy while ensuring the components remain manageable in a classroom environment. All parts were fabricated using a Bambu Lab P1P FDM 3D printer with black PLA filament, chosen for its durability and high visual contrast. The modular design enables intuitive assembly and disassembly, allowing for repeated use across instructional settings. To enhance interactivity, transparent acrylic slabs are being incorporated to support the tracing of tributary areas and visualization of load paths. Figure 1 presents a CAD-rendered perspective view of a typical story of the *Load Path Explorer*. A photo of the physical prototype is provided in Figure 2, highlighting the assembled modular frame system and its application in load path instruction.

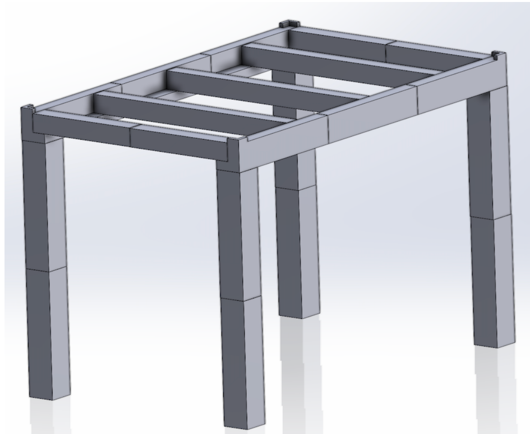

Figure 1. CAD-rendered perspective view of one story of the Load Path Explorer model.

Figure 2. Photo of the assembled Load Path Explorer prototype showing its modular structural components.

Flex Frame: Model (Under Construction)

The *Flex Frame* is currently under development and is intended to support instruction related to beam and column behavior under various loading and support conditions. This model will allow students to observe deflections and internal force patterns in real-time, helping them understand concepts such as bending moments, shear forces, and overall structural stability.

Designed using SolidWorks and fabricated with resin-based 3D printing, the *Flex Frame* will use elastic, rubber-like materials that deform visibly under applied loads. Components will include interchangeable structural members with varying stiffness levels and multiple support conditions such as pinned, fixed, and roller configurations. Weighted loads can be applied to these members to simulate structural response, while optional features like springs or visual markers will allow for exploration of internal force diagrams and deflection shapes.

Participants and Data Collection

The fourth task focuses on evaluating the impact of the Structural Learning Lab. Pre-implementation surveys were administered to students enrolled in Structural Analysis courses to assess their baseline understanding of load path concepts, spatial visualization skills, and design sequences. The results, presented in the Preliminary Results section (Figure 3), will serve as a benchmark for comparison after the implementation of the learning models.

Future work includes engaging faculty through workshops and live demonstrations to familiarize them with the models and encourage integration into coursework. The evaluation plan will incorporate pre- and post-implementation surveys, grade distribution analysis, and focus groups to assess changes in teaching practices, student understanding, and engagement.

The anticipated outcomes include an increase in faculty adoption of lab models, measured through survey results, and the development of at least three actionable recommendations for improving the models and instructional materials. Additionally, we expect to see improvements in student performance, as evaluated through grade distribution analysis in courses utilizing the lab resources. While exact percentages cannot be determined at this stage, the impact will be quantitatively assessed during and after implementation.

Preliminary Results

A pre-implementation survey was administered to approximately 50 undergraduate students enrolled in a structural analysis course to evaluate their initial understanding of structural load paths and related concepts, prior to the introduction of the *Load Path Explorer* educational tool. The survey was divided into two parts: Part A assessed conceptual knowledge through seven content-based questions, and Part B evaluated student self-confidence across four structural reasoning topics using a 5-point Likert scale.

As shown in Figure 3a, students demonstrated a strong foundational understanding in identifying basic concepts, with 87% correctly defining a load path and 65% accurately identifying the vertical load transfer sequence from slab to foundation. However, performance declined on items requiring spatial reasoning or applied knowledge. Only 57% correctly answered the question about load transfer in one-way slabs, and less than half were able to accurately classify a system as one-way vs. two-way (48%) or identify the beam with the largest tributary area (41%). Similarly, only 41% recognized that structural design begins at the top (e.g., slab) while construction starts at the foundation. These results suggest that while students grasp the general idea of how loads move through a structure, they struggle to apply this knowledge to system-level decision making or geometric relationships. This gap emphasizes the need for instructional tools that promote active learning and visualization.

As depicted in Figure 3b, student confidence aligned closely with their performance. Confidence was highest (average = 3.26) for explaining the load transfer sequence, a topic also well-answered in Part A. Confidence dropped to 2.93 when asked about differentiating one-way vs. two-way systems, and remained low for interpreting tributary areas (3.07) and understanding construction/design sequences (2.83), which were among the lowest-performing conceptual questions. These results reveal that students are aware of their uncertainty in key topics and are likely to benefit from hands-on, visually supported learning experiences to reinforce these concepts.

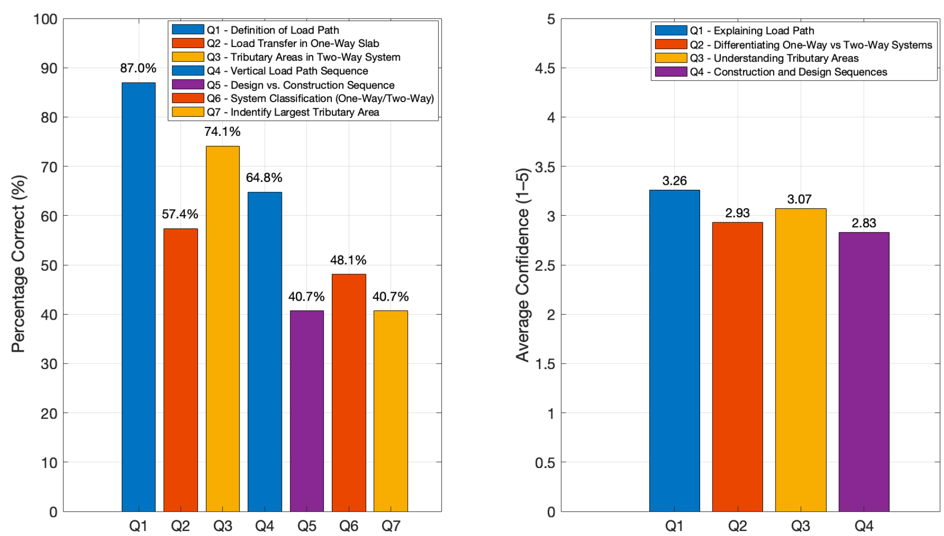

Figure 3. Results from the pre-implementation survey for the Load Path Explorer model: (a) Percentage of correct responses to conceptual knowledge questions, and (b) Average student self-confidence ratings for structural reasoning concepts.
Confidence ratings: 1 = Not confident, 5 = Very confident.
Color coding is consistent across both parts of the figure to represent shared conceptual topics.

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