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Software Applications and Pedagogical Strategies for Improving Student Understanding of Structural Analysis and Dynamics (Works-In-Progress)

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Cyber-Physical Systems and Pedagogical Strategies for Improving Student Understanding of Structural Analysis and Dynamics (Works in Progress)

Introduction

Civil and structural engineering students often have challenges with conceptual understanding of structural analysis and dynamics. Historically, students have done problem sets with images of scenarios until they had an opportunity to visit sites where models and structures have been built for testing. That is a rare occasion due to cost and space requirements unless universities have those resources or place-based education curricular priorities. By the time such forces or loads are failures after a structure is constructed, there are disastrous consequences and the scenarios become case studies in courses. Students need better tools for improving conceptual understanding of support reactions, axial forces for trusses, and shear and moments for beams via active-learning instructional activities. This paper describes the deployment of a web application that helps students develop intuition and improve their problem-solving ability by being able to see relationships in real-time. We will also describe initial lessons learned from students using the application for homework, and how we subsequently changed the course pedagogy to integrate the software.

Literature Review

Intuition helps professionals make quick and accurate predictions and decisions. It has been defined in many fields, but it has only recently been defined in engineering as "subconsciously leveraging experience to assess a present situation or predict a future outcome[1]. Intuition develops in engineering learners and is often reflected in the speed, automaticity, and engagement of information when problem-solving. Humans have a visual intuition for materials and structures we interact with on day-to-day basis and an intuition for shapes and materials that helps to negate flawed designs[2]. Yet, construction and building engineering learners must interact with materials and structures from a behavioral design perspective, predicting dynamic forces and reactions.

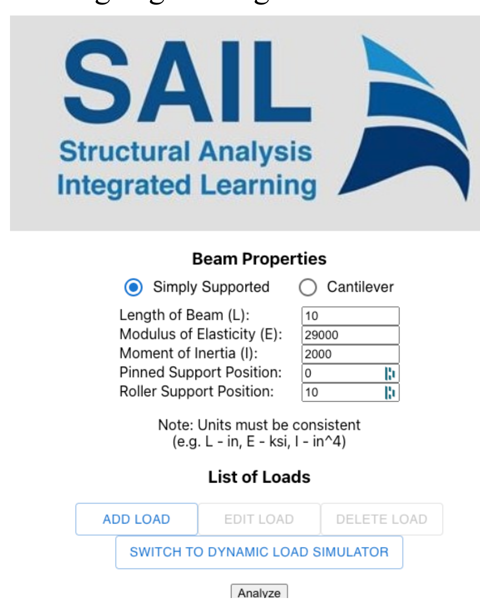


Figure 1. SAIL App web version

Application Description

This project's initial goal was to develop, test, and refine new Student-centered Cyber-Physical Systems (SCPS) tools using design-based implementation research (DBIR). Prior to the interruption of the COVID19 pandemic, the app was supposed to be a mobile application[3] that paired cell phones with physical devices and sensors supporting embodied cognition[4]. The pandemic forced a pivot to a web-based application. The SAIL (Structural Analysis Integrated Learning) App helps students model single, multiple, distributed, combined loads, and cantilever beams. It helps to teach concepts of support reactions, axial forces for tresses, and shear and moments for beams. Students can build intuitive understanding of how structures behave when they see how the values (deflection, shear force/moment, rotation, deflection) in graphic form changes in real-time. Developed and refined over three years, it now has a web version (Figure 1) and an Android version[5].

Course Implementation

The course the students would most likely use SAIL is a typically a junior level structural analysis course taken by civil or structural engineering majors who should have had a solid mechanics course prior to the structural analysis course. The class description indicates focus on analysis of determinate and indeterminate bars, trusses, beams and frames using the matrix displacement method. It also requires students to master qualitative deflected shapes and shear and bending moment diagrams. Students implement analysis procedures through computer programming using Python and commercial structural analysis software SAP2000. Students use SAIL app to help make and confirm predictions and make observations over time that improve intuition.

Research Questions

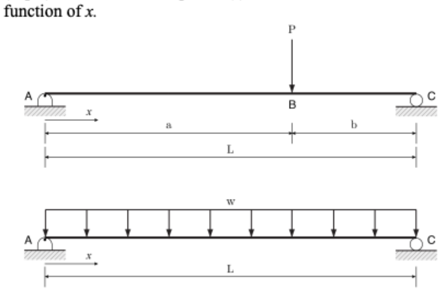
The research question of focus for this paper is: (1) How does SCPS affect student ability to sense and predict CBE (Construction and Building Engineering) problem solutions? The assessment plan includes establishing baseline data of student understanding and comparing it over time to student scores on homework and final exams. We used items from concept inventories (Force Concept Inventory [6] and Statics Concept Inventory [7, 8]) to gauge growth in student understanding of explicit concepts. Homework and exam problems were modified from these instruments.

Phase I: Deployment and piloting of SAIL

In Spring 2023, after acquiring IRB approval, the SAIL app was deployed in an upper-level structural engineering class (n=60). Students were invited to use the app to do homework problems. Five students consented to have their data used as they completed homework. We employed the predict-observe-explain (POE) cycles [9] pedagogical method to evaluate the impact of the SAIL app. This method required students to predict by choosing values for different loads, observe the instant feedback the app provided, and then explain why the model behaved as it did. This POE data was collected via a Google Form. Figure 2 shows an example homework problem and expected SAIL output. The problem set does require derivations, but alongside the use of diagrams to show relationships.

1. For the (i) concentrated force and (ii) uniformly distributed load cases shown below:

   a. (5 pts) Draw the shear force and bending moment diagrams.
   b. (5 pts) Use the CARL simulator to verify your results in (a).
   c. (5 pts) Determine the equation(s) for the shear force and bending moment as a function of *x*.



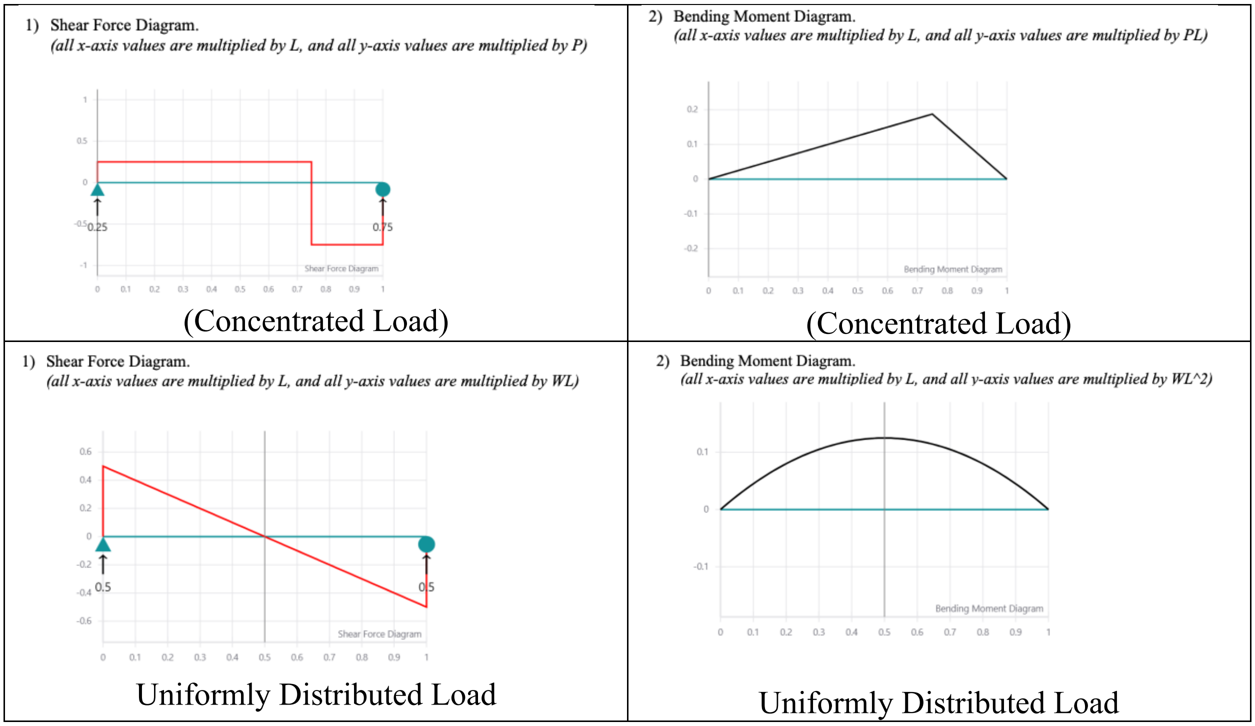


Figure 2 Example assigned homework problem and accompanying expected SAIL app output solutions.

Results

Examples of predictions and observations using SAIL are shared below:

1. ***Prediction:*** The formulas will be determined in terms of x through integration and shear/moment diagrams. The shear diagram will be a flat positive line until the force (P) interacts with the beam and then drop to a negative flat line until the end of the beam where the reaction force will balance it out. The moment diagram will be increasing linearly and then decreasing linearly at the point where the force (P) interacts with the beam, then decrease linearly until the end of the beam where it will be 0. ***Observation:*** My prediction was correct. ***Explanation:*** None.
2. ***Prediction:*** "I think the maximum deflection will be towards the left of the point load P." ***Observation:*** "the maximum deflection was slightly to the right of the point load P." ***Explanation:*** "The combined loading of the point load and the uniformly distributed loading moved the maximum deflection to the right, even though by themselves the maximums are directly under the point load and to the left."
3. ***Prediction:*** The point load will have a constant shear loading and a linear moment distribution. ***Observation:*** I ended up with a constant shear loading and a linear moment distribution. ***Explanation:*** There were only 3 points of force and no distributed loading so the shear was constant.

Findings

There were two major findings as a result of these student submissions:

- The five students had a variation in predictions. Some make shallow predictions such as the app would work and observed that it did. Those types of predictions were related to the tool rather than the concepts. Others made predictions using engineering conceptual language, observed, and explained the rationale for their observations. These kinds of predictions revealed that the app could accomplish its simulation goals.

- The kind of homework problems that require derivations of equations did not align with the predict-observe-explain actions that help students build intuition. Some students were expecting the app to help them with derivations directly instead of helping them conceptualize relationships between loads and properties. The SAIL app's goal is to help students build intuition of how a system works. They are supposed to attempt different combinations of loads and material properties to see how a bridge behaves (either before doing problems or to check HW problems that they have done). Eventually they should be able to predict the structural movement of a certain load condition without making actual calculations. So, we needed to make changes to homework to separate steps and force students to make predictions, do observations, and think about why they observed what they observed.

Phase II: Subsequent Course Changes and Ongoing Research

The research team (app developer, course instructor, and engineering educator) met to discuss pedagogical changes to the course homework to more seamlessly complement and encourage students' use of the SAIL app. Each problem was reorganized and broken down into tasks and actions that required students to explicitly use the SAIL app to predict graphs and document their predictions, observations, and explain the output of the simulation. These included training exercises (Figure 3) that required students to complete POE cycles prior to specific homework problems which would then conclude with derivations.

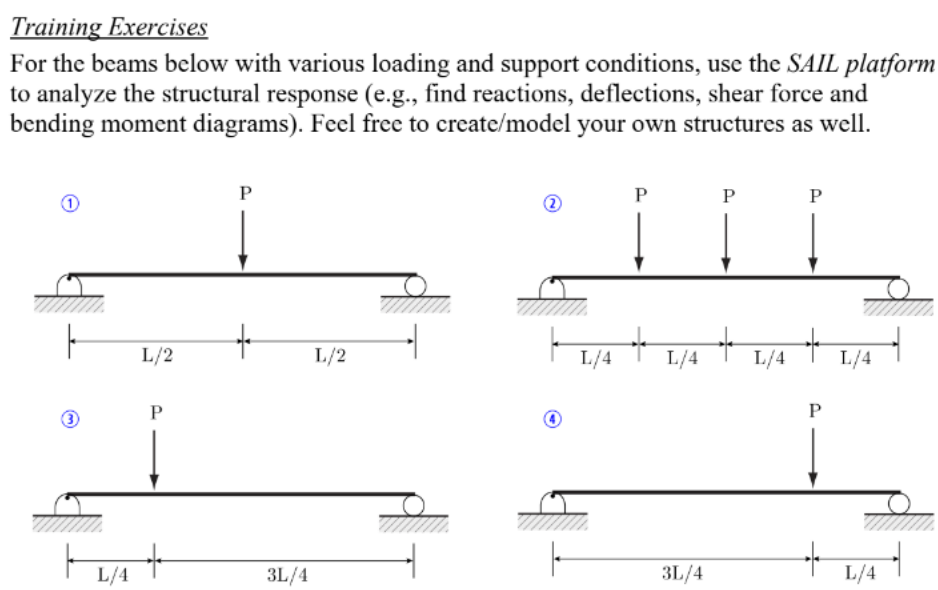


Figure 3. Training exercises that require student to interact with the SAIL app and make predictions

This homework is assigned during this current spring 2024 semester (n=45). Students worked on teams to replicate industry and submitted homework packets with executive summaries, problem solutions, and appendices. Within the homework, we explicitly asked students for feedback on use and effectiveness of SAIL to support homework completion. Ten student groups submitted homework and we share the findings from that homework. We coded the homework for themes.

Results

Finding 1: Visualization

- SAIL shows real-time visualizations along the entire beam.
- SAIL helps visualize the initial load and gives you shapes for shear, moment, rotation, and deflection. SAIL helpful in gaining a better intuition of rotation and deflection behavior of beam.
- Helps visualize properties of compound beam, giving clear max values.

Finding 2: Improves incorrect assumptions and calculations

- SAIL was helpful to prove or correct initial assumption about displacement
- Knowing this beforehand helps double check that my math is right when solving for forces for the beam. For example, it helped me realize I had the wrong equation for V(x) for the beam with the point load and it helped me check the work and answers for both beams.
- We find it easy to forget to include elastic modulus and moment of inertia, but it is impossible to not include when using SAIL…more accurate results will be produced more often.
- Equations can become long and it is easy to commit an error at any point. [SAIL] takes the long formulas out and gives useful information in a clear and concise manner.

Finding 3: Confirmation of numerical answers

- Useful to confirm numerical answer, but not useful for proof of answer.
- SAIL was very helpful and easy to use. All that had to be done was plug in all of the values of components acting on the beam and it gives an organized set of graphs and values.

Finding 4: Evidence of observation of relationships

- We found that the positions of the point load would correspond to the location of the maximum bending moment for the simply supported beam. We found that he location of the maximum bending moment [for the distributed load] was at the location where the shear changed from positive to negative.
- We found that in the point load, the max deflection shifts over closer to where the point load is applied. With the distributed load, the max deflection and deflection equation were much simpler, as you could assume symmetry.

Finding 5: Student frustrations

- SAIL does not allow conversion of units.
- Students still want to plug and play rather than look for relationships.
- We do wish the reactions were clearly labeled rather than using our knowledge of shear diagrams to determine it.

Conclusion

This implementation of the app with homework shows students not just attempting to derive equations but actually observing behavior of beams and relationships. This is positive progress since the purpose of the app is to help students improve engineering understanding and intuition and help them analyze problems and make decisions quickly. SAIL will help students who are blindly applying numbers into equations without realizing the end output does not make sense. The industry is having more and more black box tools for engineers and many of them rely on these tools. We need engineers who can quickly judge/verify whether the output from these Blackbox tools make sense or not.

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