

# Design and Implementation of a Virtual Lab in an Engineering Laboratory Course

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Instructional laboratories are an essential part of the engineering curricula, where students verify engineering theories and principles through experiments and learn their limitations. However such laboratories are often limited to various constraints such as time, space, testing equipment, variety of specimens, etc. This paper introduces a web-based hybrid laboratory as an alternative with a unique feature of combining virtual simulations and real data. As a result, students not only receive the benefits of a virtual lab, but also gain the experience of processing raw field data rather than the theoretical data generated from a computer program with built-in formulas. The database is intended to be updated regularly and will continue to expand with new data provided by engineering laboratories and educational programs. A pilot study was conducted in a small class during spring 2017. This paper details the lab development and discusses the initial findings regarding students' perceptions towards the web-based lab versus a traditional lab as well as the effectiveness of the new method based on the course assessment results.

**Key Words:** Virtual Lab, Simulations, Engineering Laboratory

## Introduction

The exciting and rapid technological advancements in recent decades have brought great challenges and opportunities to the way we teach and learn in engineering education. Instructors of traditional engineering laboratories are also exploring new methods to help mitigate negative impact from some common issues such as resource and facility constraints, safety concerns, lack of preparation, etc. As an educational lab, the learning objective is to apply theoretical knowledge and gain practical experience (Feisel and Rosa, 2005). An online environment helps the learners plan the lab in advance (Auer et al., 2003). A European collaborative project, the Go-Lab Project (Global Online Science Labs for Inquiry Learning at School) united nineteen organizations from twelve countries and provided access to a set of online science labs from worldwide renowned research institutions (Govaerts et al., 2013; de Jong, Sotiriou, & Gillet, 2014). Educators and students can greatly benefit from these labs as teaching and learning tools. In general, virtual labs are relatively low cost and maintenance, risk free, and not limited by time, space, or system configurations. Students can potentially explore a wider range of specimens in terms of sizes and material types. All of these advantages have made virtual labs a promising alternative to traditional labs.

Can practical knowledge be fully transferred and delivered through simulations? Ertugrul (1998) noted that the authenticity, constraints, and capabilities of the software could greatly affect students' experience. Potkonjak et al. (2016) points out the fact that the final stage in training usually requires real equipment. Campbell et al (2002) demonstrated that if thoughtfully designed, students with simulation experience could grasp theoretical knowledge easily when conducting experiments in a real lab. Balamuralithara & Woods (2008) suggested that the simulation environment could be improved by implementing 3D. Loughborough University, UK developed the TriLab project that provides a software package to demonstrate control system concepts by manipulating a simulated model of a physical process (Abdulwahed & Nagy, 2013).

The main goal of this research at California State University, Fresno was to design a web-based application for a traditional engineering laboratory course that had been a long-time bottleneck course in the engineering and construction management curriculums. The main reasons for it to be a bottleneck course (i.e. one that limits students' ability to make progress toward graduation) are twofold: student readiness and lab facilities constraints. The lab introduces various methods for material testing such as tension testing, torsion testing, shear testing, flexural testing, etc. The researchers created hybrid real/virtual simulations for these experiments. In other words, the simulations were built in computer programs whereas the data were collected in the field. On one hand students gain a realistic perception of field results and learn basic techniques on data processing. On the other hand, the simulations allow students to manually change controlling variables (e.g. types and sizes of specimens, loading scenarios, etc.) and observe their impact on the testing results. The number of controlling variables and corresponding test results can increase as new experiment data become available. This is a great advantage compared to physical labs which are often limited to time, space, equipment, and funding.

This paper details the lab development and discusses the initial findings regarding students' perceptions towards the web-based lab versus a traditional lab as well as the effectiveness of the new method based on the course assessment results.

## Method

This section reviews the lab development procedure and the selection of technologies regarding web and software applications, followed by an overview of the current course site layout and the first class implementation as a pilot study.

### *Lab Development*

The development of this virtual lab consisted of the following four steps:

**Step 1:** Develop a virtual lab website to contain all the course related information. The university learning management system does not provide desired custom design flexibility and software compatibility. Therefore this step was necessary. A learning module was designed for each experiment, which consisted of theory introduction, a pre-lab quiz, a lab video and notes, simulations, a post-lab quiz, and discussion board. The discussion board was intended to help create an active learning environment by engaging interactions among students as well as between students and the instructor.

**Step 2:** Create experiment models in Adobe Illustrator and then export them to Adobe Animate CC. Now the models were ready to be animated.

**Step 3:** Animate models built in Step 2 using Adobe Animate CC software. The final SWF files were embedded in the lab website created in Step 1.

**Step 4:** Collect test results from real lab experiments and upload them to the lab website.

### *Selection of Technologies*

#### *Web Application:*

Development of the web application comprises of three main parts: (1) Back-end Development (i.e. server-side coding and handling); (2) Front-end Development (i.e. the user interface, where the user interacts with the features of the website); and (3) Infrastructure Management (i.e. hosting the website on a server).

The volatile nature of web technologies and continuous rapid growth of the internet brings challenges to decision on specific languages. After assessing the objectives of the project, the researchers chose Node.js for back-end (server side) development of the website. It is one of the fast growing languages that provides solid support for the website as well as sufficient flexibility on the front-end (client side).

Meanwhile on the client side, JavaScript was selected to keep the site development flexible, as it was fully supported by Node.js. UI was developed with the help of HTML, CSS, AngularJS, and Twitter bootstrap. The website is responsive and gives users the luxury of accessing it from an array of devices.

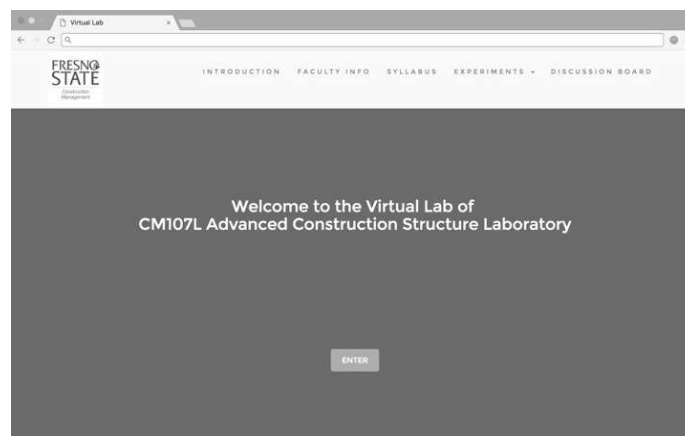
The website is currently hosted on the Heroku server, which is a platform as a service (PaaS) that enables to build, run and operation entirely in the cloud, making it convenient for researchers to continuously build and integrate.

### *Software Applications:*

Several options of software applications were explored and tested. Most failed due to the lack of flexibility. Although many JavaScript libraries (e.g., dynamics.js) support simulations for physics-based experiments, it is rare to find suitable ones for engineering material testing. As a result the researchers decided to draw and simulate the models from scratch. Adobe Illustrator and Adobe Animate CC were the two major software applications used to design and simulate the experiments. Adobe Illustrator is a powerful graphics editor used by designers to create 3D models. It provides the necessary tools to model various testing specimens and apparatus in the lab and gives these objects a real touch on the screen. Another Adobe product Adobe Animate CC, a multimedia authoring and animation program, was chosen for the ease of compatibility. The modeling files from Adobe Illustrator can be easily imported to Adobe Animate CC. Animate CC is powered by numerous features which help achieve the desired simulations in this project.

### *Current Course Site*

The current course site is a single page website which makes it convenient to navigate. Figure 1 below shows the landing page. The main course features are accessible via the top navigation bar. Users can view the course introduction, the faculty information, the syllabus, experiments (through a drop-down menu), as well as a discussion board.



*Figure 1.* Landing page of the virtual lab course website.

The learning module for each experiment is presented in the following order: “Introduction” → “Pre-Lab Quiz” → “Lab Video” → “Simulations” → “Post-Lab Quiz” – “Discussion Board”. A verification of completion mechanism was built into the system to ensure students follow the proper order and do not skip steps. Figure 2 shows the

introduction page and the lab video page from Experiment 2: Flexural Testing. The introduction section provides an overview of the leading theory, the learning intent and recommended readings. The learning module was designed and programmed in such a way that students had to enter a passcode before the pre-lab quiz to unlock the later section of the learning materials. This means students have to study the reading materials before taking the pre-quiz. The lab video page shows a short video of the experiment performed in a real laboratory, which helps students gain a visual understanding of the actual test setup. Step-by-step lab notes are provided alongside the video.



Figure 2: Introduction page (left) and lab video page (right).

After watching the lab video, students can proceed to the simulation page. As an example, Figure 3 shows simulations of two different loading scenarios for the flexural testing on wood specimens. By manually changing the A list of controlling factors such as loading scenarios, the length between end supports, and the cross-sectional dimensions are displayed below the simulation window. By manually changing one or more of these factors, the corresponding simulation and the “load vs. position” diagram will be generated accordingly. It should be noted that the “load vs. position” diagram is generated based on real test results to provide students a more realistic view of field data. To complete the follow-up questions in the post-lab quiz, students will need to make selections for the controlling factors and download the corresponding raw test results by clicking on the “Download Test Results” button.



Figure 3: Simulation pages showing different loading scenarios.

To ensure an engaging and effective learning experience to the students, a link to a designated discussion board on the Slack App is provided so students can interact with their instructor and peers.

### Class Implementation

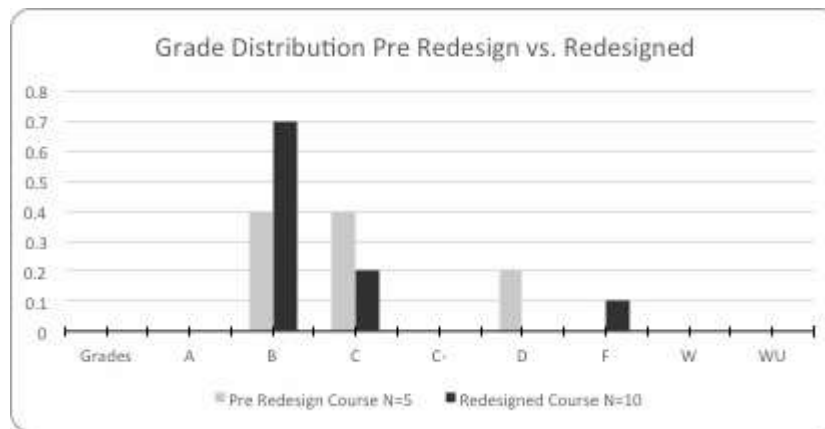
A pilot study was conducted in the spring of 2017 among a small class of 10 students. Most of the experiments were conducted in a traditional materials laboratory with the exception of three virtual experiments: Tension Testing, Torsion Testing, and Flexural Testing. A survey was distributed at the end of the semester to collect student feedback on their learning experience in the virtual lab.

## Results

Since it was a rather small class, it would be unrealistic to draw any conclusions with statistical significance. The main purpose of the pilot study was to gauge students' general interests in the virtual lab and collect feedback for future improvement.

### *Grade Comparisons*

The same lab was taught 100% in the laboratory in the fall of 2016. Figure 4 shows the grade distribution (in percentage) comparison between the two courses. The majority (70%) of the 2017 Lab received a B grade whereas only 40% of the 2016 Lab received the same grade.



*Figure 4:* Grade distribution comparison between Lab 2016 (pre-redesign) and Lab 2017 (redesigned).

The researchers also took a close look at student performance on the three virtual experiments taught online in Spring 2017. In pre-lab quizzes, the percentages of A/B grades were 90%, 80%, and 80% for experiment 1, 2, and 3, respectively. In post-lab quizzes, the percentages of A/B grades were 70%, 80%, and 60% for experiment 1, 2, and 3, respectively. Overall it indicates students were making good progress in the virtual environment.

### *Survey Results*

80% of the class completed the survey. The survey was distributed by the university to a targeted group of redesigned classes. Therefore not all the questions were relevant to virtual labs. One of the questions was "I used virtual labs or simulations in this course" with choices of answers: Always; Often; Sometimes; Rarely; Never. Six (6) out of the eight (8) students answered either "Always" or "Often". Two (2) answered "Sometimes". Then a follow-up question asked "How much did using this technology help you learn?" with choices of answers: A lot; Some; Not much; None. Three (3) out of the eight (8) students answered "A lot" while the rest answered "Some". Another follow-up question asked "How much did the website created by the instructor help you learn?" with choices of answers: A lot; Some; Not much; None. The majority of the students answered "Some" with one student selecting "Not much". The survey also asked about how often students participated in online discussion. More than half of the respondents answered either "Rarely" or "Never". Lastly, students were asked to list the top 3 activities

that helped them learn. Most students mentioned in-person activities such as hands-on testing, class collaboration, group discussions, etc. One student wrote “watching step by step videos to solve problems”. Another wrote “Taking notes (whether in class or online)”. While reading these survey results, it should be noted that most of the experiments in this class were taught in an actual laboratory. It is understandable that the hands-on experiments would leave a deeper impression on most students.

## Discussion

### *Students' Perspectives and Learning Assessment*

From the survey results it can be sensed that most students favored the traditional lab while acknowledging the usefulness of the virtual lab. There could be a number of reasons: First and foremost, the hands-on experience is very appealing, especially for a small group of class. Second, the current virtual lab is lacking group collaboration as all assignments are individual assignments. Third, the discussion board was underutilized therefore did not serve its purpose of creating an engaging learning environment. However, with thoughtful curriculum design and planning, the last two situations can certainly be improved. It should not be overlooked that although students seem to have a personal preference on the traditional lab, the grade comparisons from this pilot study indicate virtual labs may be just as effective as traditional labs, if not more. More data need to be collected to further investigate the effectiveness of virtual labs.

### *Technical Challenges*

On the technical side, properly designing and coding the application during the lab development does not guarantee a smooth run. It is critical to closely monitor the performance of the application while it is up and running. Adjustments need to be made in a timely manner to ensure the site is always catering the needs of its users.

When the educational application was hosted, one of the challenges the researchers encountered was constantly losing track of user progress from their last login. After careful investigation, the programming language was identified as the cause. A new JavaScript framework AngularJs was adopted which has the proper support of handling database state and allows the state of the user progress from the state of the database to be reflected on the UI (user interface layer).

### *Future Site Development*

Currently, the website serves its purpose of allowing the students to learn about the experiments in a virtual environment. The researchers are working on the animation of the graphs of test results to synchronize with experiment simulations. This new feature will help students gain a deeper understanding of how the experiment progresses through various testing stages.

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