

Implementing Experimental Research: A Case Study of Teaching Lateral Forces in an Introductory Structures Course

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There are many critical issues in teaching Structures courses to Building Science and Architecture students. The students seem to struggle between finding a perfect balance in learning the analytical skills and having conceptual clarity. The Building Science and Architecture students at Auburn University take two Structures courses in their sophomore and junior years. Recently, there has been a curriculum change due to accreditation needs of the Architecture program, which requires teaching impact of lateral loads in depth. It is found that traditional lecture-based methods are mostly ineffective in engaging students in the learning process. For this reason, the instructor introduced an active learning strategy in the form of an experimental research project related to lateral loads. There were three main objectives of this project: (1) to increase students' engagement and knowledge retention of the topic; (2) to apply gained knowledge to real life situations through hands on experimentation; and (3) to increase peer interaction and collaboration between Building Science and Architecture students. The project scope included building an earthquake resistant structure and testing it on a Tremor Table. Several prototypes were tested to investigate their behavior and failure modes. The paper presents background and scope of the project, its experimental design, and students' feedback along with conclusions and recommendations.

Keywords: Active Learning, Flipped Classroom, Pedagogy Development, Lateral Forces, Lateral Force Resisting Systems, Experimental Research.

Introduction

Structures of Buildings-I is a large enrolment introductory course offered to the Building Science and Architecture students in their sophomore year at Auburn University. In this course, the students are introduced to the fundamental concepts of structural analysis such as determination of gravity loads, lateral loads, and strength of materials. These students also take an advanced course (Structures of Buildings-II) in their junior year. Therefore, the conceptual clarity of fundamental principles is very important to these students. Recently, the accreditation requirements for the Architecture program are revised and resulted in more coverage and emphasis on lateral (i.e. wind and/or earthquake) loads. The paper's author (hereinafter called the Instructor) found that traditional lecture-based methods are mostly ineffective in engaging students in the learning process due to inherent complexity of the topic. It is also observed that as students take the second Structures course it becomes more difficult to retrieve the concepts they learnt in the first course (Salman and Ahmed, 2018). For this reason, the instructor introduced an active learning strategy in the form of experimental research project related to lateral loads for better understanding and conceptual clarity. Previous research shows that kinaesthetic activities have the potential to profoundly engage students in learning difficult concepts and can be very effective for teaching complex structural engineering principles (Whitehead, 2013). By experiencing and observing how various structures respond to external loads, students can discover and intuitively understand structural concepts and can better visualize the flow of forces in a building structure (Bhatia, 2015). In active learning projects, students learn by doing things, thinking about the things they are doing, and sharing the knowledge with their peers (Deshpande and Salman, 2016). There were three main objectives of the project presented in this paper: (1) to increase students' engagement and knowledge retention of the topic; (2) to apply gained knowledge to real life situations through hands on experimentation; and (3) to increase peer interaction and collaboration between

Building Science and Architecture students. The data was collected from Building Science and Architecture students at Auburn University who took the Structures-I class in Spring 2018 semester. The paper examines different tools and techniques used for this experimental research and presents assessment results by analyzing responses of the students' survey.

Literature Review

Previous research has suggested that active learning strategies in the form of demonstrations and hands-on experimentations keep students mentally and physically active throughout the class period (Gier, 2004). The instructor has been teaching Structures related courses since Fall 2016 and has experienced low motivation and lack of collaboration between Architecture and Building Science students. Hein and William's (1990) research related to active learning in Structures courses shows that "students' motivation level and degree of enthusiasm can be noticeably improved" by construction of a model structure which allow students to have a practical context for understanding the principles introduced. Research has suggested that students must become active participants in the learning process, supported by a collaborative learning environment and group work (Kamardeen, 2004). Introductory engineering/architecture courses taught with forms of active learning such as project-based learning and problem-based learning have led to increased knowledge retention of students (Knight *et al.*, 2007), improved student performance, higher quality of peer interaction, and more positive student attitude about learning (Felder *et al.*, 1998). In an effort to incorporate active learning in classrooms, a number of researchers have suggested different techniques to achieve a maximum outcome for the class. A research conducted at Princeton University was focused to transform an introductory course of Civil Engineering with research-based pedagogical techniques, and to support the dissemination of this course for STEM and non-STEM students at other colleges and universities (Bhatia, 2007). The research team listed few enhancements that have been introduced to their courses with three different activities. First, they included kinesthetic activities to engage students with principles of engineering design and external loads. By experiencing and observing how structures respond to external loads, students can understand structural concepts, and can better visualize the flow of forces in a structure. Second, they incorporated activities to a simulation software such as West Point Bridge Designer to help students visualize how forces flow through the structures. The third activity was new lecture and recitation on the topic of designing structures to withstand wind and earthquakes loads (Bhatia, 2007). It is also found that construction students are often action and result oriented whereas architecture students like to build models (Bray and Manry, 2008).

A recent study was conducted at the University of Chicago on the hands-on approach where students were involved physically in doing experiments rather than just listening or seeing the instructor perform the experiment. The study scanned the brains of students who were involved in a hands-on learning style from various STEM departments. The study concluded that students who physically experience scientific concepts understand them more deeply and score better on science tests (Ingmire, 2017). However, the learning styles are subject area sensitive and students in different disciplines require different strategies. Students are able to style-flex to their benefits as suggested by Jones and his colleagues (Jones *et al.*, 2003). Another joint study conducted by West Virginia University (WVU) and University of Akron (UA) created an effective learning environment in teaching composite materials for Civil Engineering undergraduates and introduced the use of hand-on experiments to help students grasp complex concepts. The study concluded that the major benefit to undergraduate Civil Engineering students at WVU and UA has been the effectiveness of the active learning approach. Students grasped relatively complex topic of composite materials by conceptualization through physical experiments and computer simulations (Davalos and Qiao, 2009). A different technique was introduced in Project Management classes in a study conducted at Texas State University, where students in construction classes worked as project managers from start to finish constantly contributing to the completion of their team project. Their study showed a 48% increase in students' understanding to the topic as well as 13-point increase in their grades (Torres *et al.*, 2017).

Various researches and studies have proved that model building allows students to better visualize, evaluate and understand structural engineering and construction principles (Holmes and Mullen, 2013). Motivated by these findings, the instructor designed an activity for the Structures of Buildings-I course. The aim of integrating this strategy was to increase students' engagement, knowledge retention, and collaboration in the classroom. The activity was to build a prototype of a 20-story building, apply an earthquake resisting system and test it on a Tremor table. Tremor table is a programmable shaking table that simulates the impact of an earthquake on structures.

Methodology

The impact of lateral loads on structures is a very complex phenomenon. For example, the direction and speed of wind is constantly changing. Whereas in earthquakes different waves produce different kinds of ground movement. Designers have to make sure that the building is secure against these loads up to a certain level depending upon its geographical location. The instructor, therefore, selected the appropriate earthquake loads for this first experiment. During an earthquake, three types of waves are produced; P waves, S waves, and Surface Waves. All these three waves cause the ground to move in different directions. The height, mass, and frequency also play a role in the movement of a structure during an earthquake. The concept of resonant frequency was also introduced to students via this experiment. The project assigned to students can be found in Appendix-A and the model building activity is explained below:

Step 1: Building and Testing a 20-Story Building against Earthquake Loads, Class Demonstration

For an in-class demonstration, the instructor built two prototypes of a 20-story building with a base of 40’x40’ to scale. Prototype-1 was a simple model without any lateral loads resisting system and the Prototype-2 had a bracing system. Dimensions, design, and materials were the same in both prototypes. They were built on a scale of 1” =10’. The materials used were balsa wood: five 1/8” thick floor plates to approximate the mass distribution, and a 3/4” thick foundation block. The instructor first gave in-depth lecture on earthquakes which answered simple questions like how and why earthquakes occur? What waves do they produce? How these waves cause the ground to move? These prototypes were then tested at high and low frequencies on an *earthquake tremor table* one by one. Students observed the impact of earthquake loads and measured sway for both prototypes. The testing was also recorded in slow motion for comparison and in-class discussion. Students observed a total sway of 1.5” for Prototype-1 and 0.9” for Prototype-2 (with bracing system). This in-class demonstration taught students how adding simple members (like diagonal bracing) can help to improve resistance against lateral forces.

Step 2: Building and Testing a 20-Story Building against Earthquake Loads, Students’ Experimentation

The students were given the same building prototype to build with different earthquake resistance techniques. The basic materials were also provided by the instructor so that all prototypes have consistent thickness of members and foundation blocks. The class was divided into groups of five students each. The students had to research about their assigned technique, present related case study, and mimic the technique on their prototype. The techniques assigned to the groups are listed below:

Group 1: Tuned Mass Damper
Group 2: Eccentric Braced Frame
Group 3: Base Isolators
Group 4: Shear Wall
Group 5: Moment Resisting Frame

On the demonstration day, the students presented and tested their prototypes. A measuring scale was pasted on the white board as shown in Figure 1 to measure the sway. We measured the maximum sway for each of the structure and recorded the process in slow motion for in-class discussion.

Figure 1. Students testing their earthquake resistant structures.

Figure 2. Group leaders with their models for earthquake resistant building experiment.

Students mimicked the earthquake resistant techniques on their prototypes. Cladding on the building was provided on one side only to observe the impact of earthquake. Based on their research findings, the students came up with different ideas to mimic the technique on the prototype. Shear wall had the minimum sway at maximum frequency whereas the tuned mass damper had the maximum sway. As per instructor's observations, the students highly enjoyed testing their prototypes on the Tremor table. These prototypes are shown below:

Figure 3. Tuned Mass Damper.

Figure 4. Eccentric Braced Frame.

Figure 5. Base Isolators.

Figure 6. Shear walls (model 1).

Figure 7. Shear walls (model 2).

Figure 8. Moment Resisting Frame.

Step 3: Students' Survey

Towards the end of the semester, the students' feedback was collected in the form of a questionnaire survey. The questionnaire was sent to all students at the end of the semester through Google Survey. Instructor provided time in the class to fill it out. The data was collected from 62 students. The survey consisted of questions asking about their major, year of study, and their satisfaction with the course focusing on active learning strategies in the form of experimental research.

Results and Discussion

The data was analyzed between the two majors, Building Science and Architecture. Most of the students were in their sophomore year with a little number of juniors. There was a total of 47 Architecture students and 16 Building Science students. The data was investigated based on students' perception of understanding the exercise, collaboration efforts in the class, individual and group participation, and whether the instructor should continue the active learning strategies in the future classes or not. Figures 9-14 are the responses from the students' survey when asked about their experience in an Active Learning Classroom (ALC).

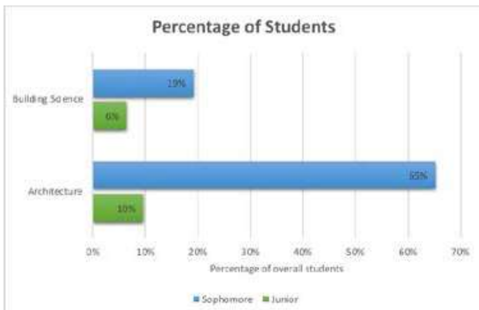

Figure 9: Composition of Architecture and Building Science students who participated in the survey.

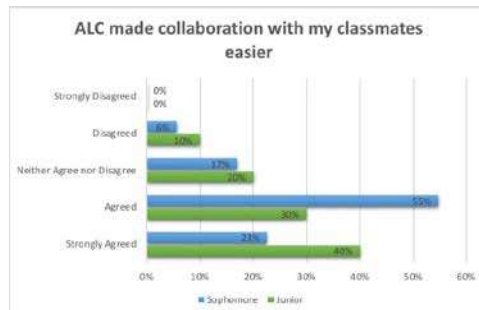

Figure 10: Graph shows that majority of students believed that Active Learning Classroom (ALC) increased collaboration among their class fellows.

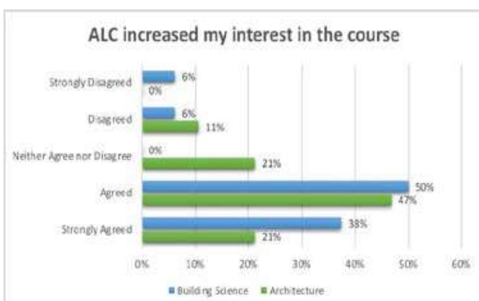

Figure 11: Majority of Architecture and Building Science student believed that the ALC has helped increasing their interest in the course.

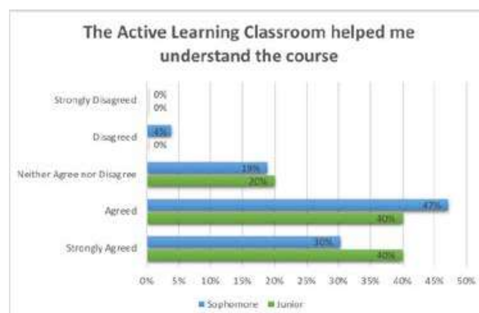

Figure 12: Majority of students agreed or strongly agreed that ALC has helped in improving their understanding of the subject matter.

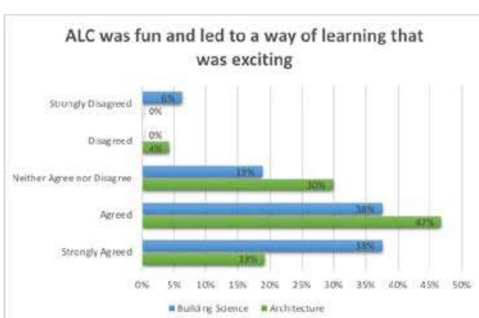

Figure 13: Majority of students believed that ALC helped in increasing collaboration.

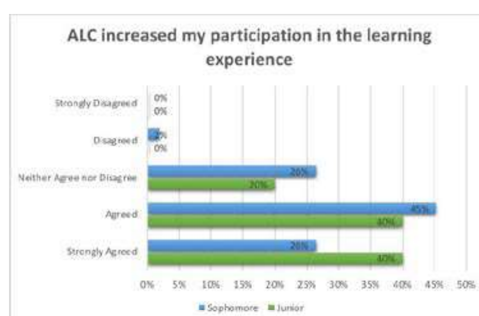

Figure 14: Majority of students believed that ALC has helped increasing participation in the learning process.

Student Feedback from the Open Ended Questions

Below are few responses from the open-eneded questions:

Question: What was one thing that you liked about your experience in this course?

- "I enjoyed working together with a team on our first-class project. I felt like everyone knew everyone and it was very clicky and that helped me to be more comfortable in class."
- "There was a better relationship between instructor and student"
- "Visual demonstrations of the concepts were nice and helped me better understand real life applications"
- "It did help with understanding the behavior of structural elements"

Question: What was one thing that you would change about your experience with this course?

- "increase aspects of participation, maybe have students work problems on the board in class"
- "Smaller groups for projects (3-4 people instead of 6-7 per group)"
- "Have more activities that required active participation"
- "More project presentations, those were very helpful to learning how these systems are different"

Question: Is there anything else you would like to share with us about your experience?

- "I enjoyed the videos and project because they helped visually reinforce some of the more complicated topics"
- "This is one of the few sciences focused classes that I have enjoyed taking"
- "The projects were a huge help, and really helped me better grasp the concepts being taught"

Conclusions

Several positives came from this exercise. First, the instructor observed that students highly enjoyed the testing days. Not only was there 100% attendance in all the sections but some students also took permission to sit in the other sections to observe their projects. The students enthusiastically participated in the discussions, shared their ideas, and expressed their desire to have more hands-on experiments in the following classes. The aim of this paper is to present active learning strategies in introductory building structures classes through experimental research. The students researched and experimented their work, which led to increased students' interest and enhanced learning experience. The instructor consistently encouraged students to participate in class to keep them motivated and interested in the course. Along with the hands-on experiments, the instructor also showed short videos related to the lessons. Based on the students' feedback and analysis of the data received from students' survey, the instructor believes the main objectives of the study have been achieved. Most of the students believed that the exercise has had helped them in their learning, collaboration with peers, and has increased their interest in the course. The instructor will continue to conduct this experiment.

Along with all the positive features of active learning classroom, there are some limitations in introducing such activities in building structures courses. The syllabus that needs to be taught in these courses is immense and certain level of analytical skills are also required in students. These experimentation take a lot of in-class time and students get confused when it comes to analytical problem solving. Therefore, durations of such activities need to be carefully designed and monitored. This was a pilot study which needs to be further refined. More research is needed to design such activities and rigorously evaluate their efficacy. The instructor has enjoyed conducting this research and hope this experience will help other colleagues to introduce such active learning projects in their classrooms.

Acknowledgements

The author would like to acknowledge the Office of Undergraduate Research at Auburn University for funding this research and partially supporting the travel.

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Appendix A

BSCI 2400-Class Project **Spring 2018**

Earthquake Resistant Structures

Purpose

The purpose of this exercise is to design and construct a model structure that will withstand the lateral forces of a simulated earthquake. You will use the earthquake resistant design techniques discussed in the class. Each group will be given a separate technique to apply on their prototype. We will then test it on the Earthquake (EQ) Tremor Table and investigate its behavior and failure modes.

Context

Your group will design a 20-story building which is approximately 200- foot high and is 40'x 40' at the base. The location of this building is San Diego, California. San Diego is considered as seismically active city since it lies on the San Andreas fault. Such a building would weigh about 1.5 million tons, so five floor plates are to be built into the structure to approximate the mass distribution to scale. Once the structural design is complete you will then apply the earthquake resistant technique listed below. Our objective is to find out the best strategy to resist lateral forces for a 20 story building in a seismic zone.

Group 1: Tune Mass Damper

Group 2: Eccentric Braced Frame

Group 3: Base Isolators

Group 4/5: Shear Wall

Group 6: Moment Resisting Frame

Materials and Scale of Prototype

Most of the material will be provided to you by your instructor. You should only use those materials to keep the weight of the structure consistent. However, you are responsible for materials for your specific earthquake resistant technique. The prototype will be built on 1"=10' scale. The basic structure will consist of balsa wood sticks, floor plates, and the tower foundation. You will also have to show some sort of cladding on the exterior, on one side only. The size of the structure will be as follows:

Exact height .... 200' (20")

Exact width .... 40' (4")

Exact depth .... 40' (4")

Number of floor plates .... 5 (at every 5th floor)

Deliverables

1. Each group will be making a power point presentation about their earthquake resistant technique with some real life examples. You should explain the technique in detail, show images and/or short videos, if available (not more than 2 minutes long).
2. Prototype

Testing

Your prototype will be placed on the EQ Tremor Table. The structure will be tested with a programmed simulated earthquake. Failure occurs when any of the plates collapses or breaks away from the structure. We will investigate the behavior/failure of each prototype. Please print the table below and record the values on the testing day.

Group Number	Technique Used	Max Frequency	Max Sway	Nature of Failure
1	Tune Mass Damper			
2	Eccentric Braced Frame			
3	Base Isolators			
4	Shear Walls			
5	Moment Resisting Frame			
Instructor	Concentric Bracing			
Instructor	No Technique			

Assessment: Total Points-100

1. **Presentation (50 Points)**
    - PowerPoint Presentation
    - 10 slides (not less not more) including the title slide
    - Use appropriate graphics and other multimedia

Following criteria will be used for presentations evaluation:

- Discussion on Earthquake Resistant Technique (20 pts)
- Related Examples (20 pts)
- Use of Photos/Tables/Videos (5 pts)
- Presentation Delivery/Preparation (5 pts)

2. **Model Building (50 Points)**
    - Neatness in design
    - Accuracy in model building
    - Innovative methods to mimic an earthquake resistant technique on your prototype.