Experiential Learning for Teaching Structural Analysis to Non-Engineering Students

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Abstract

Learning structural analysis, which is a fundamental topic for core subjects like statics, has been always a challenge for non-civil engineering students who must take statics as a mandatory course. Recent experience teaching this subject also to architecture students with limited mathematics and physics background makes learning statics very arduous for these students. To overcome these challenges, providing experiential learning experiences was sought to teach both non-civil engineering majors as well as architecture students through teaching the theory, testing in the lab, and computer simulation. Visually oriented introduction to structural theory enhances understanding of concept and fundamental of structural analysis, which is not always an effortless task even for civil engineering students. Laboratory tests help students to effectively absorb engineering courses such as statics and strength of materials. Exposing students to laboratory tests, besteads them to better visualize the connection between theoretical concepts and the experimental nature of real building structures and materials. Implementing structural modeling software is also another value that can improve students' understanding of structural analysis, particularly architecture students who have better understanding of three-dimensional visualization. Moreover, having a basic knowledge of a structural analysis software, that is compatible with Building Information Modeling (BIM) products, makes it easier and more efficient to develop design process. In this study, an undergraduate non-civil engineering class was selected as a case study and a new method was implemented to evaluate the students' learning. Results of formative assessment show tremendous enhancement of students' performance in their homework and exams from the experiential learning opportunities provided.

Background

Structural engineering deals with materials, members, loads, and the associated body of knowledge that make it possible to fabricate geometries and forms an architect conceives so that the structure meets the purpose for which it was constructed. An architect should feel what is going on in a structure without needing to count it exactly. Naturally, an important part for the future materialization of an architect's creative thought is an information chain, which finishes at the building site by the realization of the building. Maturing thought crystallization is evident also in the educational process and this is determined by the level (intellect) of students, as well as teachers [1]. In courses such as Statics, a fundamental engineering course which many architecture students find to be difficult [2-4] is an opportunity to teach fundamentals and integrate how engineers and architects work together. The difficulty has resulted in architecture students to perform poorly in Statics and other follow-on courses [5-6], which consequently has often discouraged students. On the other hand, studies on engineering students' academic achievement revealed that students who are academically successful do not necessarily have a deep understanding of fundamental concepts [7-10]. Difficulties in learning Statics are mainly due to universal impediment such as the difficult concepts, local culture and work habit of students. Therefore, learning Statics and structural analysis are more challenging for non-civil engineering students who must take statics as a mandatory course. Recent experience teaching this subject also to architecture students with limited mathematics and physics background makes learning statics very arduous for these students. In order to overcome these challenges, this study attempts to improve understanding the subject through teaching the theory along with experiential learning opportunities including testing in the lab and computer simulation.

Course Structure

The Statics course, ARCH 311, taught to architecture students (which also includes strength of materials), has several primary learning outcomes:

- Knowledge of Vector Mechanics, representation of physical quantities by a vector notation, meaning of magnitude and direction, definition of units, and mastering of Vector Algebra.
- Understanding the physical meaning of a force and a moment equilibrium, the balance of forces and moments to ensure equilibrium for 2D and 3D structures.
- Ability to identify, formulate and solve fundamental problems in Structural analysis.
- Ability to integrate the topic of structural analysis and design of individual elements and composed systems to the architectural design process.
- Ability to identify and assess the fundamental qualities of construction materials and systems, and determine appropriate materials and system for an architectural project.
- Ability to design a system, component, or process to meet the desired needs within constraints incorporating structural stability and safety.
- Ability to design and conduct experiments, as well as to analyze and interpret data.
- Understanding of professional codes.
- Ability to communicate effectively and apply professional and ethical responsibility.

Table 1 shows grading weights of this course that was taught by the first author from August 2016 through December 2016.

Table 1. Composition of ARCH 311, Fall 2016 (School of Architecture and Planning, Morgan State University)

Components	Grading Weights	Lowest Grade Dropped
Assignments	30%	No
Group Project	10%	NA
Semester Exam I	13.3%	
Semester Exam II	13.3%	Yes
Semester Exam III	13.3%	
Final Exam	20%	NA

In this course, students were exposed to the lab after the first exam to physically learn about structural analysis and material testing. During the class instructor tried to help students to understand the theoretical subjects by observing test of physical models. In addition to the lab exposures a student version of a professional software package (SAP2000 v.18) was provided for students by instructor and 2 classes assigned to teaching this computer program. The SAP2000 is a powerful platform to analyze and design 2D and 3D structures and is capable to make complex structural models. Using this software is also enables users to collaborate with other design teams with different disciplines such as architects, mechanical engineers, electrical engineers, etc. through communication with other products that are compatible with Building Information Modelling (BIM).

Methodology

In order to evaluate architecture students' performances, two methods were selected in this research.

(1) Formative assessment with comparing students' progresses during the semester, before and after exposing them to the laboratory.

(2) Comparison of final grades from architecture students (ARCH 311) with non-civil (electrical and industrial) engineering students (CEGR 304) taught by an instructor from the Department of Civil Engineering.

A sample problem of homework assignment of ARCH 311 and CEGR 304 were selected in this study to compare the level of difficulty. ARCH 311 is Statics and Strength of Materials course designed for undergraduate architecture students and data for this class was extracted from the Fall 2016 class that was taught by the first author for 16 students. The CEGR 304 is an Engineering Mechanics (emphasis on Statics) course designed for undergraduate non-civil (electrical and industrial) engineering students and data was extracted from Spring 2013, Fall 2013, and Spring 2014 classes.

Table 2. Architecture and non-civil engineering students in selected classes

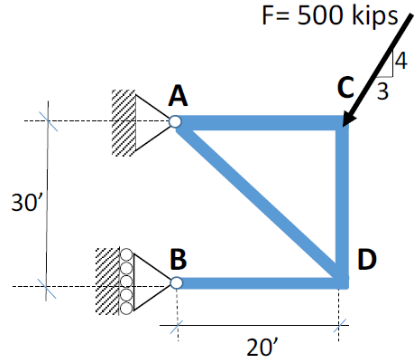
No	Course	Class	Department	Number of Students
1	CEGR 304	Spring 2013	Industrial and Electrical Engineering	36
2	CEGR 304	Fall 2013	Industrial and Electrical Engineering	11
3	CEGR 304	Spring 2014	Industrial and Electrical Engineering	27
4	ARCH 311	Fall 2016	Architecture and design	16
Total Sampling Students				90

Sample Homework Assignment of ARCH 311 and CEGR 304

The first sample homework assignment for ARCH 311 students is a truss with two pin supports and a 500-kip concentrated load with 233.1 degree direction acting on node C. Students should determine internal forces for each truss member using method of joint. The second sample homework assignment for CEGR 304 students is also a triangle shape truss with two pin supports and two concentrated loads with magnitude of 2.9 kN acting in vertical direction. For this homework, students should also determine internal forces for a 4-member truss using either method of joint or method of section.

Sample Problem (ARCH 311-MSH)

Analyze the following truss and calculate internal forces of each member, using the method of joint. [35 points]



Sample Problem (CEGR 304-SG)

Determine the force in each member of the truss. Set P_1 = P_2 = P . (a) Determine the force in member AB. (b) Determine the force in member BC. (c) Determine the force in member BD. (d) Determine the force in member BE. (e) Determine the...

Determine the force in each member of the truss. Set P_1 = P_2 = 2.9 kN .

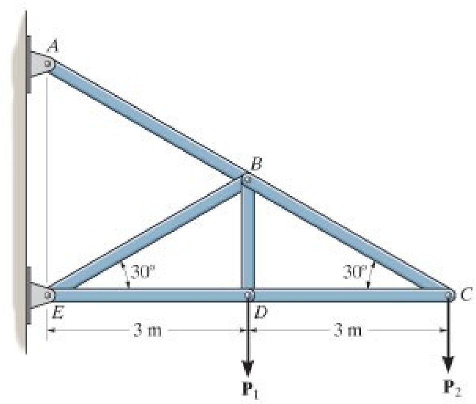


Figure 1. Sample Problems for ARCH 311 and CEGR 304

Results and analysis

ARCH 311 class performance assessment

There were 7 homework assignments for the students in ARCH 311 fall 2016 class, and three semester tests before the final exam. After the first exam, which was after the 3rd homework submission, the students were exposed to the lab and physical test of material and simple structures. Figure 2a illustrates the average students' grade for homework assignment 1 (Hw1) to 7 (Hw7), results shows about 14% decrease in Hw2 grades in comparison with Hw1. However, after exposing students to the lab, students' performances were improved by 15% in the Hw4, 13% in the Hw5, 28% in the Hw6, and 22% in the Hw7. Exposing students to the lab and learning using software to modelling simple structures, enabled students to compare what they learned in theory with their observation in the lab and the model they created in the software (SAP2000). Figure 2b shows the exam grades for each students in this class. There were 3 semester exams and one comprehensive final exam. The results show that after exposing students to the lab and learning experience for structural simulation, students' performances were improved by 11% for the Exam II, 10% for the Exam III and 5% for the comprehensive final exam.

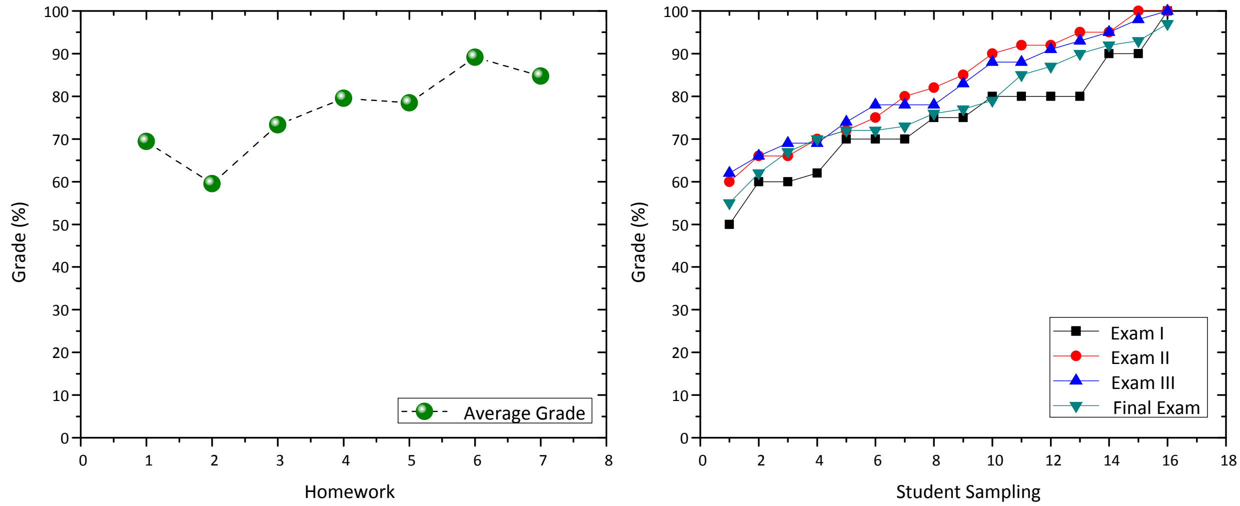


Figure 2. Assessment of students' performance in ARCH 311 fall 2016 class, (a) average grade for homework, (b) students' grades for semester tests and final exam

Comparing performance of architecture with non-civil engineering students

In order to assess architecture students' performances a comparative study is conducted between architecture students in ARCH 311 and non-civil (industrial and electrical) engineering students in CEGR 304 for three sequential semesters. The CEGR 304 spring 2013 class had 36 students, fall 2013 class had 11 students and spring 2014 had 27 students. Figure 3 shows results of this comparison to clearly evaluate students' performances in architecture and non-civil engineering classes. The figure illustrates the final grade of students for each class and reveals that ARCH 311 students performed even better than the non-civil engineering students (with math and physics background) by 12.1% higher final grades compared with the average of 3 non-civil engineering classes, where similar experiential learning opportunities were not provided showing value in this exposure.

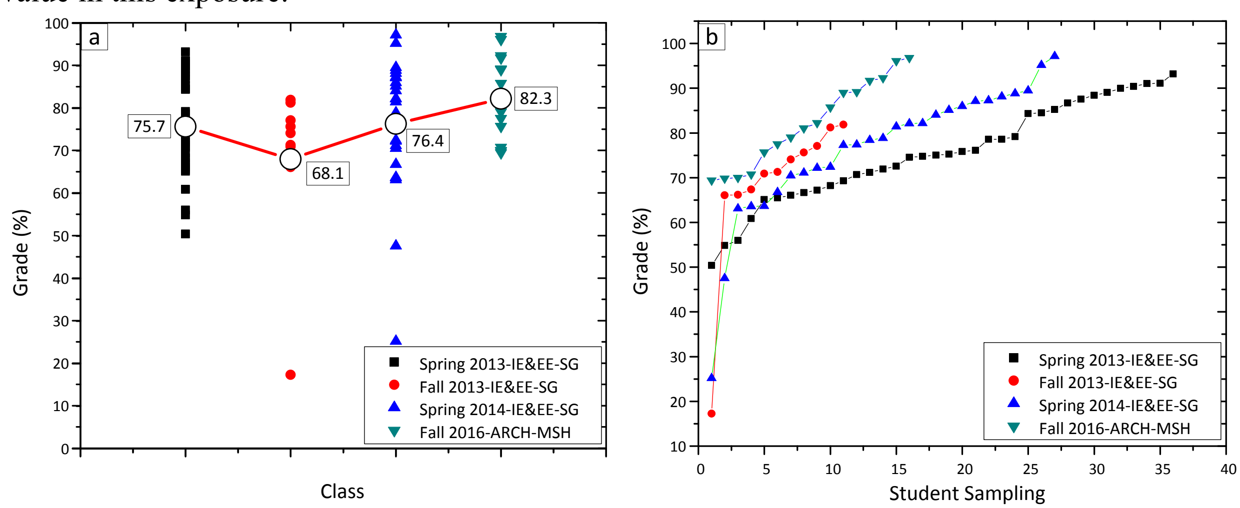


Figure 3. Comparative study between ARCH 311 and CEGR 304, (a) average of final grades, (b) grades for each student in class

Conclusions

A total of 90 sampling students in ARCH 311 (Statics and Strength of Materials) and CEGR 304 (Engineering Mechanics) courses at a Historically Black College and University were studied to assess architecture students' performance in their class and to compare with non-civil (industrial and electrical) engineering students, where similar gaps of understanding exist. The aim of this study was to determine the effect of exposing students to the lab and learning basic structural simulation on better understanding the theoretical subjects. Overall results show that the use of this teaching method aids in improving student grades, thereby suggesting an enhancement of student learning. Although students are given multiple attempts for homework that resulted in an increase in homework grades, the semester tests, final exam and consequently, final grades also improved. Results shows architecture students' performances were improved in each homework after exposing students to the lab and by 22% in the last homework assignment. The students also had improvement in the exams, by 11% in the Exam II, 10% for the Exam III and 5% for the comprehensive final exam. The comparison between architecture and non-civil engineering students (Industrial and Electrical Engineering) shows that ARCH 311 students performed better than CEGR 304 students by 12.1% higher final grades. In addition to the conducting physical tests and learning simulation software, it is expected that incorporating construction site visits, where students can experience real-life structural systems, would be beneficial to improve students understanding topics and even examples used in a Statics course to bring relevance and more context.

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