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Introducing the SEE laboratory for the enhancement of engineering education

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ABSTRACT: In this article, the authors report an undergraduate educational engineering research project as part of the AIMS2 (attract, inspire, mentor and support students) programme funded by the United States Department of Education. It involved the design, construction, instrumentation, experimentation, theoretical analysis and numerical simulation of three structural physical models, vis. a single-story, single-bay portal frame and a pair of beams with different support and loading conditions, and a portable platform, the so-dubbed SEE (structural engineering encounter) laboratory, entirely conducted by undergraduate and college-level students under the supervision of Drs Zirakian and Boyajian at California State University, Northridge (CSUN). The products of this research endeavour are envisioned to be used for enhancing the comprehension of engineering concepts, developing new avenues of undergraduate engineering research and taking full AIM (i.e. attract, inspire, mentor) at future undergraduate engineering students. This successfully-implemented programme can serve as a model for engaging a diverse student population in universities offering engineering programmes in order to prepare a brighter future within the engineering profession.

Keywords: Engineering education, active-learning, undergraduate research, SEE laboratory, recruitment tool

INTRODUCTION

Research has shown that active and project-based learning methods have been effective in motivating student comprehension and levels of interest in engineering education. Combining traditional lecturing with hands-on activities through teamwork has been instrumental in educating the next generation of critical thinking and problem-solving engineers. Holzer and Andruet [1], Felder et al [2], Davalos and Qiao [3], and Dodge et al [4] showed that hands-on learning experiences and enhanced laboratory environments improve the understanding of engineering concepts for students. Springer et al investigated the importance of students studying in small groups and showed that such approaches are effective in promoting greater academic achievements [5]. Alcorn found that the quality of structural engineering education was enhanced when enabling students to test theoretical concepts in a hands-on, laboratory environment to supplement the instruction they had received from their engineering statics class [6]. Carlson and Sullivan, to counter the more traditional *chalk-talk* lecture format, conceived of the integrated teaching and learning (ITL) programme to exploit teaming, active learning, and project-based design and problem-solving experiences [7]. They found that such an approach heightened student interactions by keeping them more alert and engaged during the lesson, culminating in a greater overall learning outcome. Davies made a case for the important benefits that are gained through practical work experiences when coupled within the engineering curriculum [8]. In this vein, she lists: a greater motivation to the students achieved by stimulating their interest in the subject; a deepening of their understanding when relating theory to practice; the benefits reaped through working together with their peers when analysing and solving engineering problems; and the development of skills and attitudes to enable graduates to operate effectively and professionally in the engineering workplace.

Davies cites the work of Gibbs et al who recommended pragmatic approaches that concentrate on achieving *higher level aims*, i.e. those that go beyond the mere learning of how to operate a piece of equipment, for instance [9]. Eight various activities are therein listed: 1) the development of experimental, design, problem-solving and analysis skills; 2) developing data-recording and analysis skills; 3) familiarising students with equipment techniques and materials; 4) developing practical skills; 5) developing communication and interpersonal skills; 6) developing technical judgement and professional practice; 7) integrating theory and practice; and 8) motivating students. In addition to physical models for students to get their literal hands on, Huynh et al, used a virtual reality (VR) system that combined both hardware and software to simulate the buoy-wave interaction phenomenon [10]. The unit they developed was portable, thus enabling it to be taken to students in different high schools, with the outcome of bringing exposure of such important scientific concepts to a diverse body of students. They also conducted surveys of the participants at the two high schools that they visited and received very positive feedback. Prior to this study, Mayrose had likewise developed a VR environment to offer students an immersive environment over the traditional lecture approach [11]. He created two parallel lessons on the subject of forces and motions. One, in the latter, traditional lecture style, and the other, using the former VR system. For these two control groups, which consisted of 180 students in total, he found that students who were exposed to the immersive VR environment made greater gains in learning.

Considering the importance and benefits of active and project-based learning with the aim of developing a strong link between theory and practice as demonstrated through the prior research, an undergraduate research programme was designed and implemented by two faculty mentors, Drs Boyajian and Zirakian, at California State University, Northridge (CSUN). This programme involved the design, construction, instrumentation, experimentation, numerical simulation and theoretical analysis of three structural engineering-based models conducted entirely by a group of college and undergraduate students. These efforts culminated in the conception of what has now been dubbed as the structural engineering encounter physical and portable laboratory (SEE laboratory). This research endeavour was made possible through the AIMS2 undergraduate programme grant as funded by the Department of Education with the aim of attracting, inspiring, mentoring and supporting Hispanic and low-income students at CSUN. The three major objectives of this educational research programme include: 1) enhancing the comprehension of engineering concepts; 2) developing new avenues of undergraduate engineering research; and 3) taking full aim at future undergraduate engineering students, which are discussed in this article.

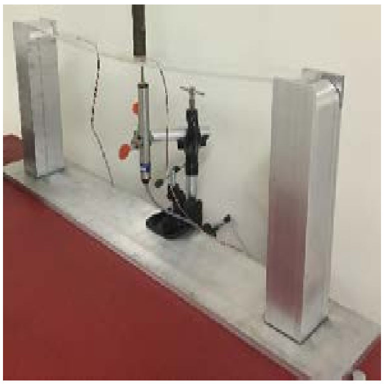
SEE LABORATORY

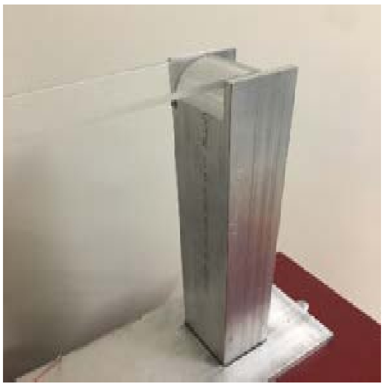
Experimental Details

The first phase of this educational research endeavour was to have students to design, fabricate, instrument and test structural models to afford them, as well as future generations of engineering students, to participate in unique active learning experiences in the structural engineering discipline. The faculty mentors, Drs Zirakian and Boyajian, conceived of, and hence dubbed, the structural engineering encounter laboratory, or SEE laboratory for short.

To this end, a pair of beams with simple-simple and fixed-fixed support conditions, as well as a single-story, single-bay, portal frame were designed, fabricated, instrumented and tested by the student researchers. The beams of all the models had a span length of 61 cm (24 in), the columns of the portal frame were 46 cm (18 in) long, with cross-sectional dimensions of all elements being 5 cm × 0.6 cm (2 in × 0.25 in).

In order to obtain maximum rigidity and stiffness, aluminium was used for the supports and the base plate. The supports were screwed to the plate for easier assembly and proper strength. In addition, a portable testing platform was constructed by the team to enable the placement, experimentation and exhibition of the physical models to showcase the SEE laboratory to a diverse population of high school-, college- and university-level students. The details of the constructed SEE laboratory are illustrated in Figures 1 and 2.

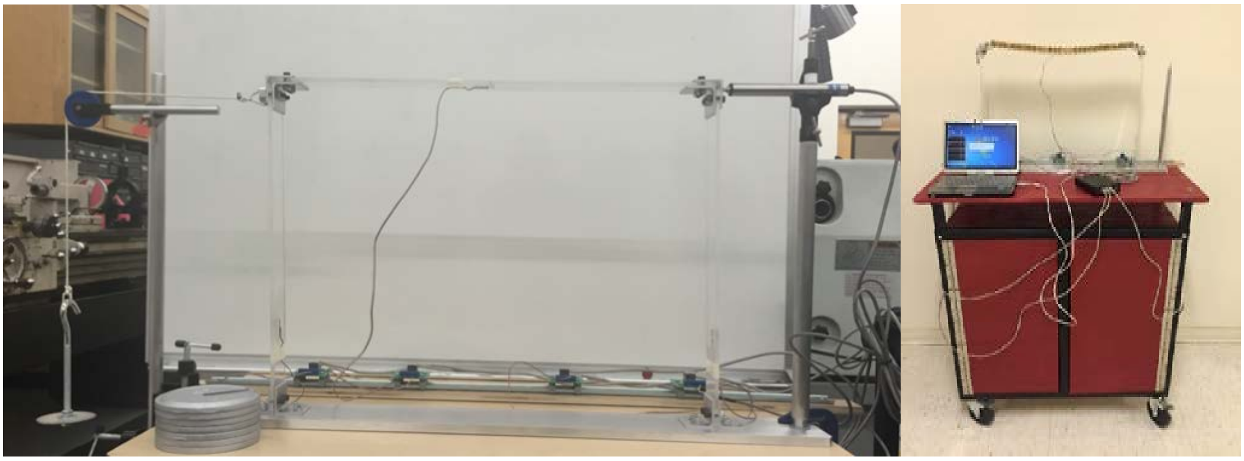

a)


b)


c)


d)

Figure 1: Testing platform: a) and b) beam with simple-simple end supports; c) and d) beam with fixed-fixed end supports.



a) b)

Figure 2: Details of the constructed SEE laboratory: a) portal frame; b) portable platform.

The chief material used in the fabrication of the physical models was Plexiglas. In order to determine the precise material properties, tensile tests were done on four dog-bone specimens. The tensile test specimens, as well as the stress-strain relationships are shown in Figure 3. The average Young's modulus of E = 3.05 GPa (0.442 Msi) was subsequently used in theoretical calculations and numerical simulation.

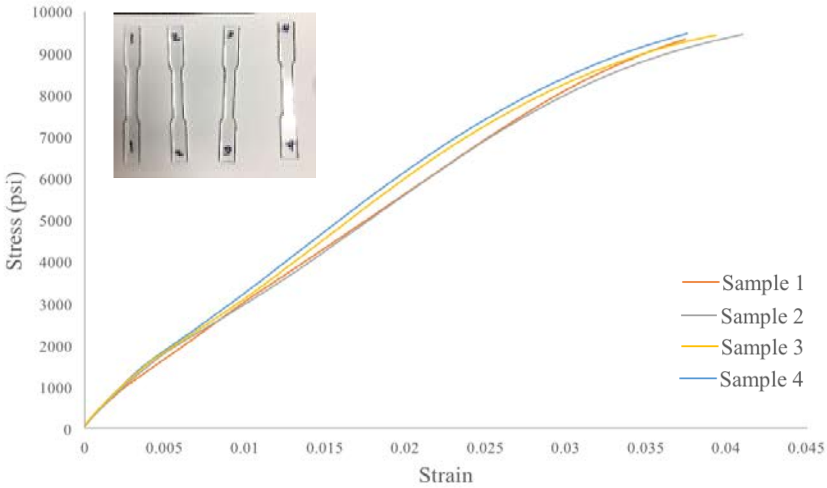


Figure 3: Tensile tests.

The beams were instrumented by two strain gages mounted at the quarter- and mid-points, and a linear differential variable transformer (LVDT) was used to collect deflection readings at midspan. The portal frame was instrumented by three strain gages mounted at the beam midspan and the third points of the columns nearest the supports, and an LVDT was used to capture the lateral displacement of the frame. All readings were digitally captured via a data acquisition system (DAQ). The details of the instrumentation are shown in Figures 1 and 2.

The two beams and the portal frame were subjected to uniformly distributed and midspan concentrated loads. The vertical loadings were applied by means of stacking standard cylindrical masses, either side-by-side for the distributed loading case or one on top of the other, for the point load case. For added precision, these masses were weighed using a scale balance. Furthermore, the portal frame was subjected to lateral loading through the use of a pulley system utilising hanging weights.

Theoretical Analysis

The importance of theory in evaluation of experimental observations and findings was discussed at the outset through interactions with student researchers. Through such a mentorship, the students were guided to gain knowledge in regards to theoretical predictions of beam behaviour under different loading and support conditions. In this vein, they were also instructed to learn about the effects of different geometrical and material parameters in determining the deflections of beams, such as load intensity, beam span length, Young's modulus of the material and moment of inertia of the beam cross section.

It is important to note that theoretical calculations of deflections were only made for beams with simple-simple and fixed-fixed support conditions, as the two extreme boundaries having established closed form equations. In this regard, explanations were provided concerning the fixity of the end conditions of the portal frame beam, which is considered as being partially restrained at the ends, with no explicit closed form equations to predict beam deflections. Accordingly, some comparisons and evaluations were made by the students which are discussed later.

As explained before, beams with simple-simple and fixed-fixed support conditions subjected to midspan concentrated and uniformly distributed loads, were considered in this study. The theoretical expressions summarised in Table 1 were gathered through the research efforts of students charged with the task of exploring various loading and support conditions of the beams under investigation.

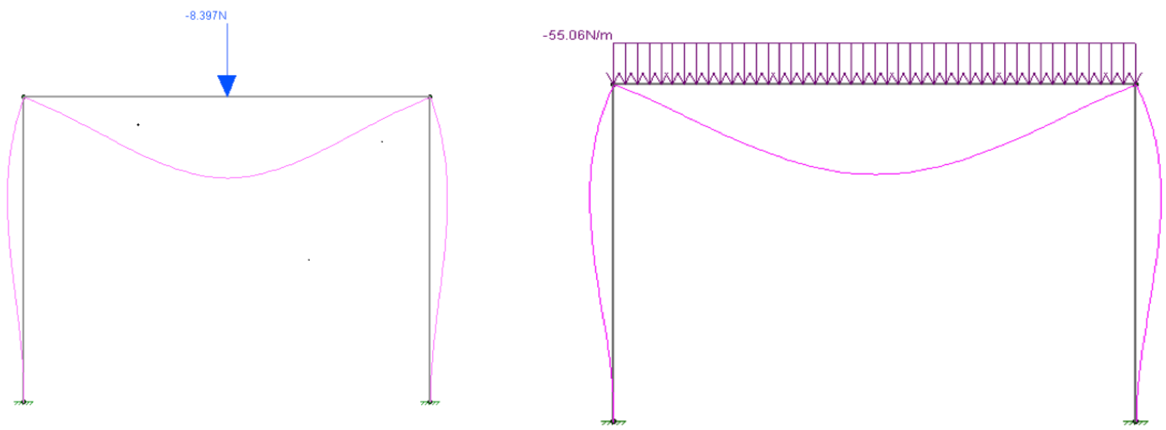
Table 1: Expressions for beam midspan deflection calculations.

Support condition	Loading condition	Midspan deflection
Simple-simple	Concentrated at midspan	$\delta_{theo,ss} = \frac{PL^3}{48EI}$
	Uniformly distributed	$\delta_{theo,ss} = \frac{5wL^4}{384EI}$
Fixed-fixed	Concentrated at midspan	$\delta_{theo,ff} = \frac{PL^3}{192EI}$
	Uniformly distributed	$\delta_{theo,ff} = \frac{wL^4}{384EI}$

Numerical Simulation

In addition to theory, the research team was also introduced to the importance of numerical modelling and analysis. During these early discussions with the student research team, various analytical tools, e.g. ANSYS, ABAQUS, ETABS, SAP, etc, as commonly used in engineering practice, were discussed, and RISA-2D was settled upon as the tool of choice for this study. On this basis, the student researchers were instructed to learn about the simulation details in RISA-2D in order to accurately model and analyse the structures.

It is noted that this program allows for detailed simulations based on the inputted dimensions, material properties, loading scenarios and boundary conditions of the structure. The deflections of the beams with different support (simple-simple, partially restrained and fixed-fixed) and loading (midspan concentrated and uniformly distributed) conditions were predicted numerically, which are discussed in the subsequent section. Two typical numerical models under midspan concentrated and uniformly distributed loads are shown in Figure 3.



a) b)

Figure 3: Numerical models of the portal frame under different loads: a) midspan point load; b) uniformly distributed load.

Discussion of Results

The experimental results and theoretical, as well as the numerical predictions for the simple-simple, fixed-fixed and portal-frame beams under point and uniformly distributed loads, are summarised in Tables 2, 3 and 4, respectively. Despite some scatter in the results due to experimental conditions and theoretical as well as numerical idealisations, the agreement between the results is overall quite satisfactory.

In actuality, the beam of the portal-frame is only partially restrained, a condition that lies between the two extremes of the simple-simple and fixed-fixed supports, as displayed in the last two columns of Table 4. Evaluation of the experimental and theoretical results summarised in Table 4 reveals an 81% rotational fixity, on average, for the end supports of the portal-frame partially restrained beam.

Table 2: Summary of results for midspan deflection of the beam with simple-simple supports.

Loading	$\delta_{Num.-SS}$ (mm)	$\delta_{Exp.-SS}$ (mm)	$\delta_{Theo.-SS}$ (mm)
Point	22.85	23.31	22.85
Distributed	57.13	70.93	57.13

Table 3: Summary of results for midspan deflection of the beam with fixed-fixed supports.

Loading	$\delta_{Num.-FF}$ (mm)	$\delta_{Exp.-FF}$ (mm)	$\delta_{Theo.-FF}$ (mm)
Point	4.54	5.57	4.54
Distributed	9.08	9.33	9.08

Table 4: Summary of results for midspan deflection of the portal-frame beam.

Loading	$\delta_{Exp.}$ (mm)	$\delta_{Num.}$ (mm)	$\delta_{Theo.-SS}$ (mm)	$\delta_{Theo.-FF}$ (mm)
Point	7.54	9.88	21.63	5.41
Distributed	21.83	22.74	54.08	10.82

EDUCATIONAL OBJECTIVES

Enhancing the Comprehension of Engineering Concepts

A primary goal inherent to the teaching of engineering is to ensure students understand the basic fundamentals and theoretical concepts. As students have different learning abilities and a variety of ways to assimilate information, accommodations ought to be made to address these needs effectively. An important expectation in this vein is for the professor to engage students to be active participants in the learning process. With this expectation, the professor can function as a facilitator in the learning process, rather than the mere deliverer of information.

To construct a link between the gaining of theoretical knowledge by students in the classroom to the host of broad applications within the field of civil engineering, a key aspect to achieving this goal is to ensure students understand the assumptions used in developing the theoretical and empirical concepts, and their respective limitations in practice. Development of such educational pedagogies including experimental, theoretical and numerical aspects, will enable the students to learn the principles behind the engineering and mathematics concepts, which, in turn, enables them to apply these principles in a variety of settings, e.g. subsequent engineering courses and in professional practice.

Developing New Avenues of Undergraduate Engineering Research

The products and outcomes of simple engineering research projects can provide opportunities for other fruitful and even advanced undergraduate research experiences. In the case of the current research programme, construction of the physical models has paved the way for conducting further studies on the behaviour and performance assessment of structures. For instance, the original single-story, single-bay portal frame is now currently being adapted for mounting on a shake table to evaluate its seismic performance. Moreover, the beam structures with different support and loading conditions, can be utilised to investigate criteria, such as serviceability limit states. It is evident that well-designed educational learning projects can even engage undergraduate students in the investigation of cutting-edge areas of engineering research. Together, all of these activities lend themselves in educating well-prepared engineers, professionals and life-long learners.

Taking Full AIM at Future Undergraduate Engineering Students

As the acronym of the funded project, AIMS2, which stands for attract, inspire, mentor and support students, here the main objective is to take AIM at future undergraduate engineering students. To this end, it is crucial to demonstrate the importance and attractiveness of the engineering sciences for alluring up-and-coming generations of students to this most significant area of education. The attracted and inspired students of today will, in the not too distant future, assume places of leadership in the sustainable development of the society of tomorrow. As an example, the constructed physical models along with the portable platform, i.e. the SEE laboratory, enables the mentors and the undergraduate research assistants to showcase these novel learning tools to inspire and recruit high school and college-level students in pursuing engineering studies.

CONCLUSIONS

The AIMS2 research programme, provided an opportunity to engage undergraduate students in fundamental, as well as simple research projects with experimental, theoretical and numerical aspects. This project involved the design, construction, instrumentation, experimentation, theoretical analysis and numerical simulation of a single-story, single-bay portal frame, as well as a pair of beams with different support and loading conditions all performed by undergraduate and college-level students under the supervision of Drs Zirakian and Boyajian at CSUN.

Through this programme, the participating student research assistants learned of the theoretical and practical aspects of civil and structural engineering. The products of this research endeavour are envisioned to be used for: 1) enhancing the comprehension of engineering concepts; 2) developing new avenues of undergraduate engineering research; and 3) taking full AIM (i.e. attract, inspire, mentor) at future undergraduate engineering students.

As demonstrated in the current undergraduate educational research project, engagement of a diverse student population including minorities, women and underrepresented, as well as first-generation students, in a baccalaureate-granting institution can result in preparation of a more balanced future engineering professionals. This will, in turn, contribute to the economical and sustainable development of the society. Lastly, it is quite important to note that all of this can be successfully achieved through the development of well-designed and simple research projects.

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REFERENCES

1. Holzer, S.M. and Andruet, R.H., A multimedia learning environment for statics. *Proc. ASCE Structures Congress XII*, Atlanta, GA, 1, 308-314 (1994).
2. Felder, R.M., Felder, G.N. and Dietz, E.J., A longitudinal study of engineering student performance and retention - comparisons with traditionally-taught students. *J. of Engng. Educ.*, 87, **41**, 469-480 (1998).
3. Davalos, J.F. and Qiao, P., Effective teaching and learning of composite materials for undergraduate civil engineering students. *Proc. 2003 American Society for Engng. Educ. Annual Conf. & Expo.*, American Society for Engng. Educ., 10 (2003).
4. Dodge, R.E., Fisher, B.C., King, J.J., Kuehl, P.G., Matsuki, S., Mitchell, W.E., Dailey, J.F. and Boyajian, D.M., Introducing the Structural Engineering Encounter laboratory: a physical approach to teaching statics, mechanics of materials and structural analysis. *World Trans. on Engng. and Technol. Educ.*, 9, **2**, 86-91 (2011).
5. Springer, L., Stanne, M.E. and Donovan, S.S., Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. *Rev. of Educ. Research*, 69, **1**, 21-51 (1999).
6. Alcorn, C.G., Improving Student Knowledge through Experiential Learning - a Hands-on Statics Lab at Virginia Tech. Project Report submitted to the faculty of the Virginia Polytechnic Institute and State University for partial fulfilment of the requirements of the degree of Master of Science in Architecture, Construction Management Option (1997).
7. Carlson, L.E. and Sullivan, J.F., Hands-on engineering: learning by doing in the integrated teaching and learning program. *Inter. J. of Engng. Educ.*, 15, **1**, 20-31 (1999).
8. Davies, C., *Learning and Teaching in Laboratories. An Engineering Subject Centre Guide*. Higher Education Academy Engineering Subject Centre (2008).
9. Gibbs, G., Gregory, R. and Moore, I., *Teaching More Students: 7 - Labs and Practicals with More Students and Fewer Resources*. Oxford: Oxford Centre for Staff Development (1997).
10. Huynh, T., Hou, G. and Wang, J., Communicating wave energy: an active learning experience for students. *American J. of Engng. Educ.*, 7, **1**, 37-46 (2016).
11. Mayrose, J., Active learning through the use of virtual environments. *American J. of Engng. Educ.*, 3, **1**, 13-18 (2012).

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