Neoclassical Active Learning Approach for Structural Analysis

Julio F.Davalos, Christopher J.Moran, Shilpa S.Kodkani

West Virginia University

Abstract

Most beginning students in an introductory structural analysis course do not appear to have a sound understanding of fundamental concepts, and in general, students lack the ability to visualize the deformed shapes of simple structures. One possible reason for this learning deficiency may be that the classical lecture-mode of teaching by itself may not be sufficient for students to grasp basic concepts, and a more active classroom participation by students may be needed. The objective of this study is to provide an interactive and a collaborative, team-oriented classroom environment for students to explore theoretical concepts through physical experiments and computer modeling. The primary guiding principle in the development of the laboratory modules is constructivism, which was implemented by creating an experiential learning environment through the use of active learning techniques. The laboratory sessions provide an opportunity for students to enquire, explore, collaborate, and have fun while learning. Eleven laboratory modules have been developed, covering topics from static equilibrium to the measurement of displacements and strains for beams, frames and trusses. The laboratory provides an excellent forum for experiential learning, whereby an experience is transformed into knowledge. The final result is a comprehensive teaching approach that efficiently merges theory, computer modeling, and experiments into an exciting learning environment. The use of an active learning approach has proved to be successful in enhancing the ability of students to master the fundamental topics of structural analysis. The development of active learning environments should be considered for other engineering courses where students have difficulty with fundamental concepts or where the ability to visualize physical behaviors is essential in understanding and mastering the course material.

Overview

We present in this paper laboratory and computer activities, which are designed to complement the lecture portion of an introductory structural analysis junior-level course in Civil Engineering curricula. The objective is to create an effective environment for students to dynamically participate in their own learning by adopting an "active learning approach," which combines classical methods of analysis with laboratory experiments and computer modeling.

Most beginning students in an introductory structural analysis course do not appear to have a sound understanding of fundamental concepts, such as equilibrium of forces and free-body diagrams, and in general, students lack the ability to visualize the deformed shapes of simple structures. One possible reason for this learning deficiency may be that the classical lecture-mode of teaching by itself may not be sufficient for students to grasp basic concepts.

> *Developing instructional strategies to help students learn to think creatively and critically has become recognized as one of the most pressing educational challenges facing faculty today. On this subject, the advice of the experts is clear: Students will not learn how to successfully perform these skills by listening to lectures that attempt to model these difficult intellectual tasks.*[1]

During the six-year development of the concept discussed in this paper, students have demonstrated that they can use the laboratory exercises developed in this study as efficient vehicles to better grasp fundamental concepts while enjoying "hands-on" experiences with structural behaviors of physical and computer models.

The development of the laboratory modules was conducted in the context of "neoclassical active learning" approach for effective learning and teaching of structural analysis. The combination of classical methods with computer-aided analysis is termed a neoclassical approach to engineering,[2] which in combination with laboratory experiments was implemented in this study. The goal was to provide interactive, collaborative and team-oriented classroom environments for students to explore theoretical concepts through physical experiments and computer modeling. The primary guiding principle in the development of the laboratory modules is *Constructivism*, supplemented by *experiential learning* in the context of *active learning* techniques.

The laboratory sessions provide an opportunity for students to enquire, explore, collaborate, and have fun while learning. They also provide an excellent forum for experiential learning, whereby an experience is transformed into knowledge. Students in teams of three or four participate in laboratory activities that consist of either physical experiments or computer modeling. The commercial computer program used provides an opportunity for students to explore the behavior of complex structures, including the experiments conducted in the laboratory sessions. Moreover, the use of the computer program reinforces the learning of fundamental concepts, such as free-body diagrams and equilibrium of joints and members.

For each laboratory session, students submit a laboratory report following the guidelines given in the laboratory manual. [3] In addition to the report, student teams make presentations on a specific assigned topic of the Discussion and Questions section of each laboratory session. Also, student teams are asked to present 15-minute mini-lectures on assigned fundamental concepts during the class period. These activities are designed to foster the continuous learning principle: "learning… is what virtually all adults will do for a living by the beginning of the 21st century." [4] The implications are: Learning will be a life-long journey; your well-being will depend on your learning skills. [5] The final goal is to design a comprehensive teaching approach that efficiently merges theory, laboratory experiments, and computer modeling into an exciting learning environment.

Active Learning

There is no unique definition of active learning. We can examine its meaning by the combined effect of the words ″active″ and ″learning″, as the primary definition of ″action″ followed by the secondary definition of ″learning″ from Merriam Webster's Internet dictionary. [6]

Active: characterized by action rather than by contemplation or speculation.

Learning: knowledge or skill acquired by instruction or study.

It follows that an active learning approach implies that the student is a dynamic participant in his acquisition of skills and knowledge. The responsibility of the instructor then becomes the creation of an efficient environment for students to actively participate in their own learning. [5]

Bonwell and Eison [1] in a report for the Association for the Study of Higher Education define the characteristics of active learning as: "students are involved in more than listening; less emphasis is placed on transmitting information and more on developing students' skills; students are involved in higher-order thinking (analysis, synthesis, evaluation), and students are engaged in activities (e.g., reading, discussing, writing)." Thus, greater emphasis is placed on students' exploration of their own attitudes and values. They further state, "…in the context of the college classroom, active learning can be defined as anything that involves students in doing things and thinking about the things they are doing."[1]

Our motivation for implementing an active learning approach was to promote in students: higher involvement, better retention of fundamental concepts, and increased enthusiasm. Active learning environments can significantly enhance short-term retention of information by students (see Figure 1). The attention span of an average student wanes quickly in traditional lecture formats. [7] In teaching structural analysis, the earlier in the course the students grasp fundamental concepts the more effectively the instructor can move on to more advanced topics. The use of active learning techniques is an effective means to help students grasp fundamentals of structural analysis early in the course: "…. students learn as much or more when alternatives to traditional lectures are used." [1] Based on the students' performance on exams, the current preliminary results of the present study have shown that more material can be covered in greater detail in a semester and with a better understanding by the majority of the students. The performance of our students exposed to the present active learning environment has shown to be significantly better than in previous traditional lecture-type setting, as measured by test, quiz, homework, report and presentation results, as well as student surveys.

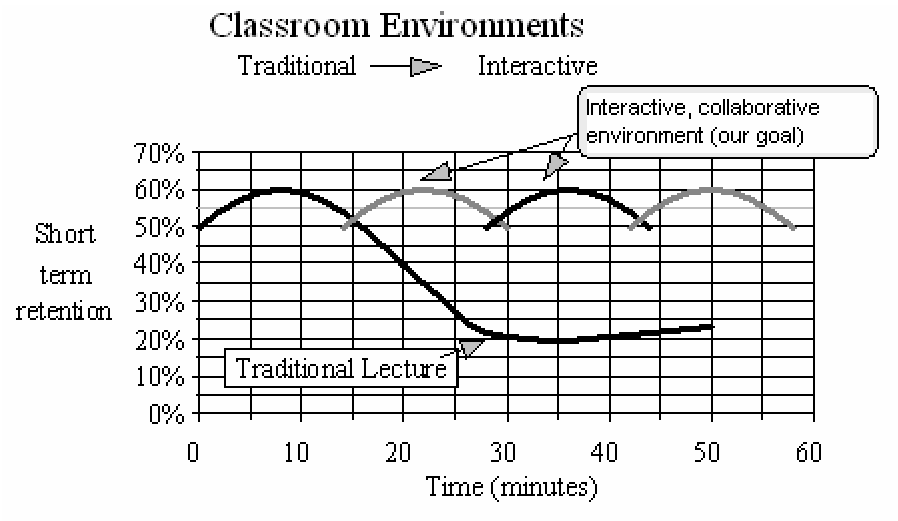

Figure 1 Short-term retention in two types of classroom environments [8].

With respect to the effort invested by the teacher on active learning approaches, it is difficult to dispute the statement that "…devising strategies promoting active learning takes too much preparation before class." [1] The use of an active learning approach does require constant attention and dedication by the teacher. An instructor who embraces this type of teaching approach must be willing to make the students' learning his first priority. The material developed in this study can serve to reduce the amount of effort required by the instructor to design a course in structural analysis based on active learning approach.

Experiential Learning

An active learning approach can be effectively based on experiential learning. Experiential learning, in general, is the formation or creation of knowledge through experience. An experiential learning model consisting of a four-stage cycle was proposed by Kolb [9] based on the contributions of the works of Dewey [10] and Piaget. [11] The premise of this model can be stated as: "the process of learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world." [9] It can be seen that the experiential learning process is cyclic in nature. At closer inspection this model is similar to the scientific method, as follows: concrete experience = observe behavior or experiment, reflective observation = analysis or problem definition, abstract conceptualization = hypothesis, and active experimentation = testing.

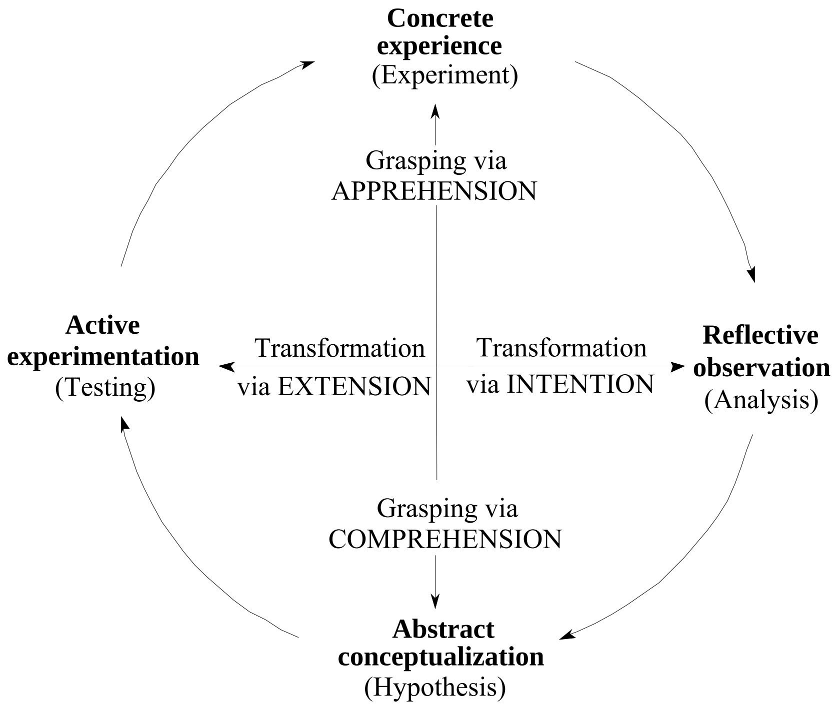

Figure 2 Model for experiential learning and associated knowledge forms [9].

In Kolb's [9] model there are two pairs of dynamically opposite learning modes: concrete experience vs. abstract conceptualization and reflective observation vs. active experimentation. Learning occurs when conflicts between these opposite learning modes is resolved. The concrete experience vs. abstract conceptualization learning is called prehension and is based on Piaget's [11] figurative aspect of thought. The reflective observation vs. active experimentation learning mode corresponds to Piaget's [11] operative aspect of thought. To accommodate different types of learners, as discussed for example by Kolb, [9] it is advisable to incorporate all four components of the model shown in Figure 2. For more information on different models of learning, see the work of Richard Felder. [12]

Constructivism

The principle of constructivism [11] can be expressed as: "knowledge must be constructed by the learner; it can not be supplied by the teacher." [13] This same idea is given by the Farsi proverb: *A well must produce its own water*. The implications are: "We are all responsible for our own learning; the teacher is responsible for creating an effective learning environment." [5]

A constructivist approach prompts us to ask questions such as "How do we know what we know?" and "How can people claim to know what they say they know?" Constructivism requires that each of us build our own knowledge. This is in contrast to dissociative or passive traditional teaching methods where the involvement of the students in the learning process generally ranges from minimal to moderate. Constructivism is by definition subjective and places significant emphasis on the inductive abilities of students rather than on memorization skills. Under the constructivist approach it is the responsibility of students to integrate new building blocks into their knowledge base, and the task of the instructor is to provide an environment in which the students can engage in the creation of their own knowledge. In a constructivist environment students are naturally forced to make an assessment of what they already know and what they need to know to master a concept.

Constructivism and experiential learning are complementary concepts: taking responsibility of and engaging in our own learning. The concepts of constructivism and experiential learning are both primarily based on the work of Piaget. [11] Constructivism requires that the learner actively participate in the acquisition of knowledge, and similarly, experiential learning requires the engagement of the learner. Kolb's [9] model of experiential learning is an effective application, and even an illustration, of the constructivist approach. Guided by constructivism, our task was to implement experiential learning concepts into practice.

Laboratory Topics

Eleven laboratory modules have been developed and they can be classified into three types: large deformations, computer analyses, and instrumented laboratories. The large deformations laboratory modules are intended to allow the students to examine the exaggerated deformed shapes of beams, trusses and frames. The computer analyses laboratories are designed to instruct the students in the fundamentals of computer modeling of structures using software based on the matrix displacement method. The three instrumented laboratory modules are designed to increase the students' understanding of basic relationships of strain-stress vs. internal forces and the prediction and measurement of displacements of structures. The sequence of the large deformations laboratory sessions, as noted by numbers in parenthesis, includes the following topics: (1) *Principle of Equilibrium,* (2) *Deformed Shapes of Beams,* (4) *Locations of Inflection Points,* (5) *Deflected Shapes of Frames*, (7) *Inflection Points in Frames* and (8) *Deflected Shapes of Trusses*. There are two computer analyses laboratories: (3) *Computer Analysis of Structures I: Beams*, (6) *Computer Analysis of Structures II: Trusses and Frames.* The last three laboratory sessions include instrumented structures and consist of: (9) *Displacement and Strains in Beams*, (10) *Displacements and Strains in Frames* and (11) *Displacements and Strains in Trusses*.

Implementation of Active Learning

Objective: Our primary objective was the development of an active learning approach for effective teaching and learning of structural analysis, by providing an efficient environment for students to grasp fundamental concepts through the use of laboratory experiments and computer simulations, which were designed to continually enhance and support the classical lecture topics; a neoclassical approach.

Constructivism was the guiding principle used to develop the laboratory component and was applied by implementing an experiential learning environment through the use of active learning techniques. The laboratory modules were designed to expose the students to physically observe and study the behavior of structures; students were guided in their thinking by linking the laboratory activities to the lecture topics.

The development of the laboratory modules is in part based on Kolb's model [9] of experiential learning (Figure 2) which includes a four cycle process: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. The laboratory activities in this study follow this model at two levels, inside the organization of individual laboratories and as a series of three or four laboratory sessions.

Laboratory Sessions: The organizational structure of each of the laboratory sessions is much the same: Introduction, Objective, Background, Equipment, Experimental Procedure, and Discussion and Questions. The two computer analysis laboratories use an expanded version of this structure.

The laboratory is laid out to start Kolb's [9] cycle with the Abstract Conceptualization phase. This is accomplished by having the students read the first three sections of the laboratory module: Introduction, Objective, and Background. The Introduction and Objective sections set the goals of the laboratory, and the Background section provides the students specific information on theoretical concepts. The information provided in the Background section is intended to initiate the thinking of students about the material of the upcoming laboratory and as a foundation for the students to build their hypothesis on.

The laboratory activity corresponds to Kolb's [9] Concrete Experience phase, where the students conduct "hands-on" experiments and summarize their results; this is similar to the Observed Behavior step in the scientific method. The data reduction exercises and conceptual questions are written to make students think about, or analyze, how the structures behaved; this corresponds to Kolb's [9] Reflective Observation phase of the learning cycle. Finally, the additional problems assigned from the laboratory manual, for cases not specifically tested, can be considered to satisfy the Active Experimentation phase.

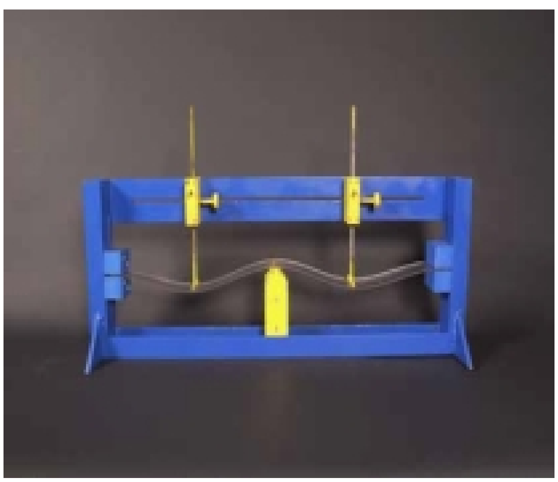

Figure 3 Clamped ends and concentrated loads

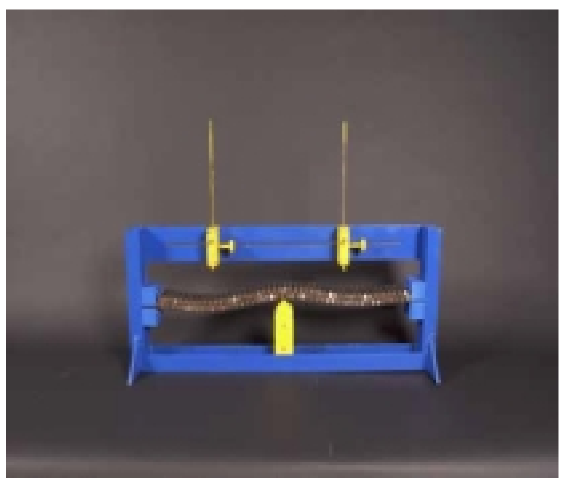

Figure 4 Clamped ends and distributed load

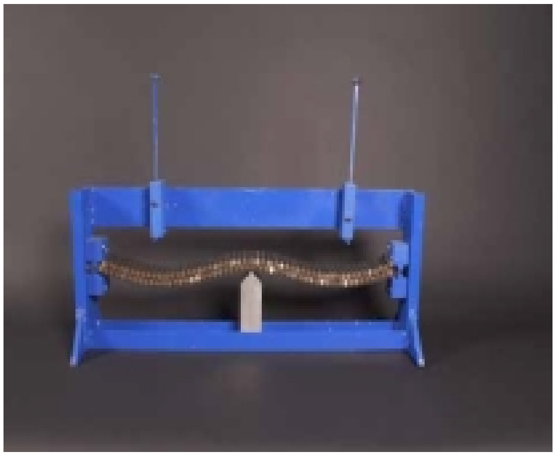

Figure 5 Pinned ends and distributed load

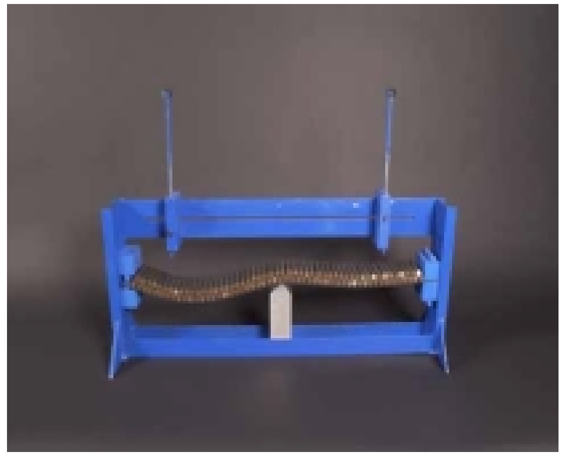

Figure 6 Pinned-end and clamped-end and distributed load

Application - Laboratory Modules for *Deformed Shapes of Beams*: Consider as an example Laboratory 2: *Deformed Shapes of Beams* to illustrate the applications of Kolb's[9] experiential model. The background section of the laboratory manual discuses member stiffness and describes the fundamental relationship between the deformed shape and shear and moment diagrams; two examples are provided to illustrate this relationship. The material presented was selected to assist the students in their understanding of the concept, supplemented by classroom lectures, and leading to postulate a hypothesis to be actively studied during the laboratory session. Then, the experimental cases were chosen to show how the characteristics of the applied loads and prescribed boundary conditions affect the deformed shapes of the beams. To illustrate this concept, similar structures but with different boundary conditions and load cases are deflected to show that the resulting deformed shapes are quite different, as can be seen in Figures 3, 4, 5 and 6. The ideal approach, time permitted, would be to have the students draw the shear and moment diagrams after each experiment, rather than to conduct all the assigned cases and then sketch the shear and moment diagrams. During the laboratory and after conducting a few of the experimental cases, the students are encouraged to sketch the expected deformed shapes before applying the loads. By experimenting with several cases, many of which are more complicated than the examples presented in the manual, the experiments do more than just confirm the background material; they expand on it and create new experiences and therefore new knowledge.

The data reduction activity is designed to force the student to think about what they have experienced in the laboratory. As stated above, if time permitted during the laboratory, it would be more effective for the students to sketch the shear and moment diagrams before conducting each experimental setup, but this is not practical, and therefore, all of the data reduction or analysis is performed later. The activity of sketching the shear and moment diagrams for the experimental cases completes the Analysis phase of the model in Figure 2. Then, the remaining assigned conceptual questions constitute the Testing phase of experiential learning.

As Kolb's[9] model is a cyclic process, which expands the learner's knowledge each time it is completed through conflict resolution, the cycle can be repeated to increase the student's knowledge. This is accomplished, for example, by following the first laboratory on beams (laboratory 2) with three more that examine the behavior of beams in more detail. The first two physical laboratories on beams (laboratory 2 and laboratory 4) are conceptual in nature, and the data reduction does not require any numerical calculations; the shear and moment diagrams are drawn to conceptually conform to the deformed shapes observed by the students. In contrast, the beam modeling laboratory, *Computer Analysis of Structures I*: *Beams,* demands a different but complementary action; the construction of the shear and moment diagrams is based on the computer output with rigorous calculations of values at key points. The laboratory sessions of testing of beams were intended to give the students physical understanding of structural behavior, so when they construct moment and shear diagrams based on computer analyses, they would have the ability to evaluate whether or not their results make physical sense. From the above experimental and analytical activities, students can formulate hypotheses with confidence (phase 3 of the model).

The fourth beam laboratory, *Displacement and Strains in Beams*, is conducted later in the course. This module is the most complex of the beam laboratories, and it is intended to significantly increase the students' understanding of the behavior of beams. In the context of experiential learning this laboratory provides a core scientific approach to confirm the beam behaviors observed in the large deformations and the computer modeling modules. This laboratory can be considered to correspond to Kolb's[9] Active Experimentation or Testing phase, as it can be used to confirm the students' expected beam behaviors based on their experiences with the other beam laboratories. In addition, this module is also used to explore fundamental stress-strain relationships and advanced topics dealing with displacement components due to shear. This organization of laboratory modules was intentionally designed to complement several laboratory sessions, and the same protocol was adopted for the frame laboratory modules.

Laboratory Activities and Lecture Topics: The active learning activities, which are organized in eleven modules for the laboratory component of the course, are designed to effectively complement the lecture topics that are typically included in an introductory course: (1) Equilibrium and Reactions; (2) Shear and Moment Diagrams for Beams and Frames; (3) Plane Trusses; (4) Deflections for Determinate Structures; (5) Indeterminate Structures and (6) Selected Topics.

For the most part there is a one-to-one correspondence between some of the laboratory modules and the lecture topics listed above. For example, Laboratory 1- Equilibrium, was developed and scheduled to support the first lecture topic on Equilibrium and Reactions. The experiments are designed to be physically similar to the types of problems normally assigned as homework for this topic. The generation of Shear and Moment diagrams is a requirement of almost every one of the laboratory modules, which provide continuous support for this relatively difficult topic. The large deformations modules are extremely useful for developing fundamental understanding of the deflected shapes of beams, frames and trusses; this understanding is an essential component for the efficient use of the various classical methods typically available to calculate deflections. It is imperative to have the ability to sketch the deformed shape in order to efficiently apply the best analytical method to compute deflections. The study of deflections is further reinforced by the last three laboratory modules, which are designed for students to develop sound understanding of displacements and strains in beams, frames and trusses.

Applications of Combined Active Learning Activities: The specific activities which have been incorporated into the present concept are: computer based instruction, cooperative learning, demonstrations, discussions, experimentation, reading assignments, student generated questions, student presentations, student projects, tests and quizzes, and visual based instruction. The way each of these active learning activities has been utilized is given in detail by Moran. [14]

Selected photographs of experiments for several laboratory modules are shown in Figure (7) – Large Deformations of Frames, Figure (8) - Instrumented Beams, Figure (9) - Instrumented Frames, and Figure (10) – Instrumented Truss.

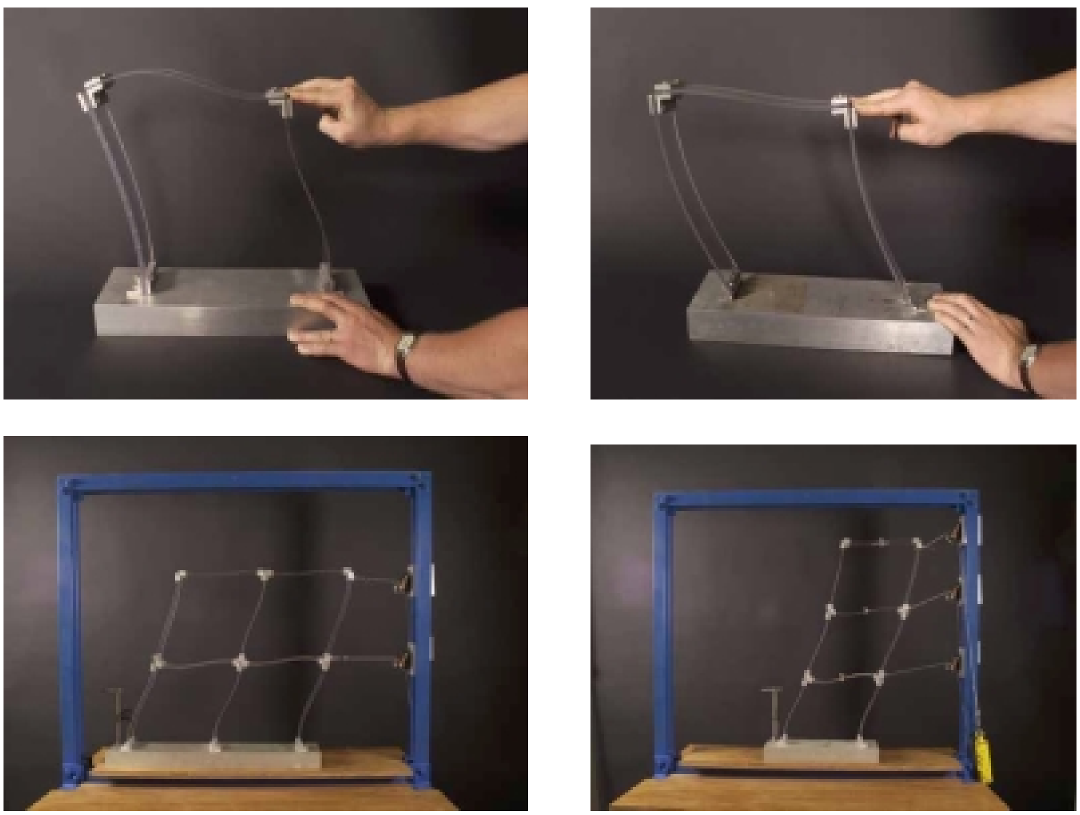

Figure7 Large deformations of frames

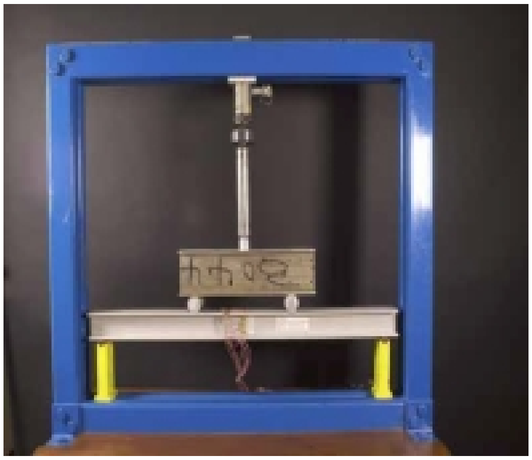 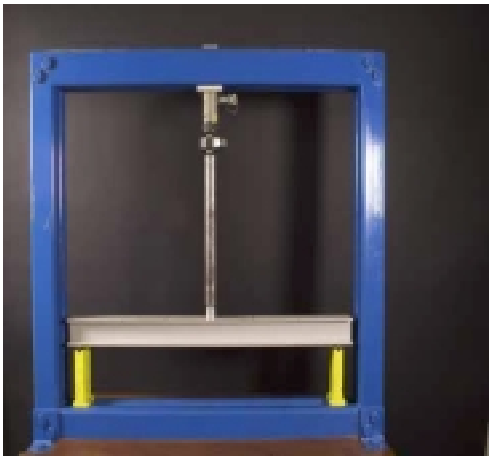

Figure 8 Instrumented Beams

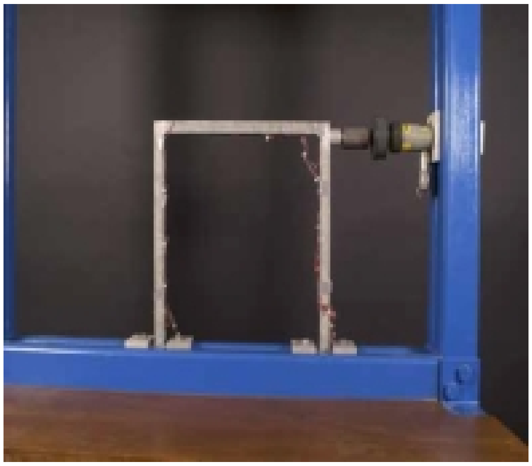 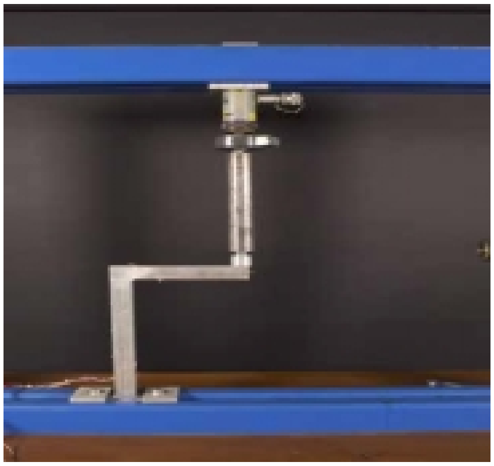

Figure 9 Instrumented Frames

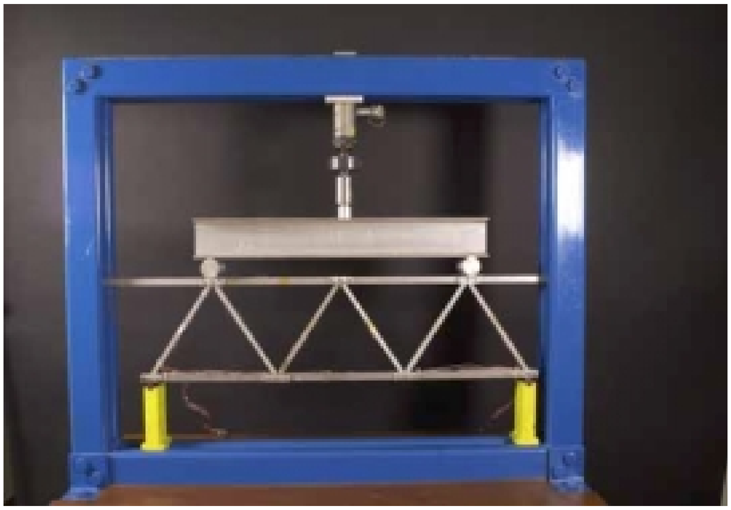

Figure 10 Instrumented Truss

Concluding Remarks

Based on the success of the present study, the use of active learning environments for other engineering courses should be considered. Introductory courses seem to be the best candidates for this type of approach, and active learning approaches are recommended for courses such as statics and dynamics. The use of this type of approach for selected advanced topics can also be effective, in courses such as advanced materials or design applications.

In conclusion, we believe that this study has met its objective of creating an effective learning environment for the students to dynamically participate in their own learning through the use of active learning techniques. The laboratory experiments and the computer modeling exercises complement efficiently the lecture portion of the course. The students involved in this course have shown to better grasp fundamental concepts of the behavior of structures and have the ability to easily predict the deformed shapes of structures.

No formal assessment of learning outcomes was conducted. However, the authors have had the opportunity of teaching this course within the traditional format of 3-credit-hour lecture and later as the present 4-credit-hour “active learning” course discussed in this paper. Given the formality with which curriculum changes are implemented in the university and lack of opportunity for teaching multiple sessions in a semester, it was simply not possible to teach this new concept in relation to a “control” group under the classical format; thus, we are unable to provide quantitative data of the benefits of the innovations described in this paper. But, based on student evaluations of instruction, performance in quizzes, tests, and projects, and numerous favorable comments and testimonials, we are convinced that the environment discussed in this paper significantly facilitates and enhances the learning of students, an we would not go back to the traditional approach, but rather continue to explore and improve the present innovations.

Bibliography

1. Bonwell, C.C. and Eison, J.A., *Active Learning: Creating Excitement in the Classroom,* The George Washington University, School of Education and Human Development, Washington, DC, 1991.
2. French, S.E., *Fundamentals of Structural Analysis*, West Publishing Company, St. Paul, MN, 1995.
3. Davalos, J.F., and Moran, C.J., “Laboratory Manual for Structural Analysis: An Active Learning Approach,” Department of Civil and Environmental Engineering, West Virginia University, 1996, Revised 1998.
4. Perelman, L.J., “The End of Education,” *Washington Post Education Review*, November 1, 1992.
5. Holzer S.M., 1994, “From Constructivism to Active Learning,” *The innovator*, The SUCCEED Newsletter, No. 2, spring 1994, pp. 4-5.
6. *WWWebster Dictionary*, Merriam Webster, http://www.m-w.com.1997.
7. Verner, Cooley and Dickson G.,” The lecture: An Analysis and Review of Research,” *Adult Education*17: 85-100. American Association for Adult and Continuing Education, Chapel Hill, NC.
8. Felder, R.M., SUCCEED Teaching Effectiveness Workshop, North Carolina State University, Raleigh, NC, June 10-11,1994.
9. Kolb, D., *Experiential Learning*, Prentice Hall, Englewood Cliffs, NJ, 1984.
10. Dewey, John. 1938, “Experience and Education”, Reprinted 972, Collier Books, NY.
11. Piaget, J., The Construction of Reality in the Child, Basic Books, New York, NY, 1954.
12. Felder R.M., “Matters of Style”, ASEE Prism, *6*(4), pp.18-23, December 1996.

13. Holzer S.M. and Andruet R.H.,“ A Multimedia Learning Environment for Statics,” *Proceedings ASCE Structures Congress XII*, Atlanta, GA, 1994. Vol. I, pp.308-314.
14. Moran C.J., “Active Learning Approach for Structural Analysis,” M.S. Thesis submitted to the College of Engineering and Mineral Resources of West Virginia University, 1997.

About the Authors

JULIO F. DAVALOS
Julio F. Davalos is the C.W. Benedum Distinguished Teaching Professor at West Virginia University and Professor of Civil and Environmental Engineering, with B.S., M.S., and Ph.D. in Civil Engineering from Virginia Tech. He received numerous teaching and research awards including four-times Teacher of the Year in the College (1995, ‘96, 2000, ‘01), WVU Outstanding Teacher (1995), Professor of the Year in the State of West Virginia (1998). His research expertise includes structural mechanics, advanced materials, and innovative teaching methods and technologies.

CHRISTOPHER J. MORAN
Chris Moran obtained his M.S. degree in structural engineering from WVU (1997). He is a professional engineer working in design of highway bridges for J&T Engineering in Baltimore, MD.

SHILPA S. KODKANI
Shilpa Kodkani obtained her B.S. in Civil Engineering from Karnataka Univ. (1998), India, and she is currently pursuing her M.S. degree in structural engineering at WVU. Her research is concerned with interface mechanics of fiber-reinforced composites externally bonded to concrete; a rehabilitation technology widely used for retrofit of highway bridges, particularly for seismic response, and other concrete and masonry structures.