Build It and They Will Learn: Enhancing Experiential Learning Opportunities in the Statics Classroom

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Engaging construction management students in the statics classroom is a difficult task. However, ensuring their comprehension of simple structural behavior is even more challenging. Using large-scale, in-class models and demonstrations has proven to be one way to increase both the experiential learning opportunities in the classroom and student understanding of basic physical systems in static equilibrium. This paper discusses the philosophical background to experiential learning and specifically focuses on the statics classroom. Detailed descriptions are given of the physical models created by the authors for classroom demonstrations. The preliminary results from an on-going study into the effectiveness of these models reveal that both the students' quiz performance and their feelings about the class instruction improved when models are used to demonstrate concepts introduced during lecture.

Key Words: Experiential Learning, Statics, Undergraduate Construction Education, Pedagogy, Physical Models

Introduction

The study of engineering mechanics, and specifically physical systems in static equilibrium (statics), is a crucial component in the education of professionals entering the construction field. While only a very small portion of construction management students' future professional careers will involve the design of structures, with the notable exceptions of temporary structures and residential structures, the main purpose for construction management students taking a course in statics is to prepare them to understand the behavior of simple structures. "Behavior" is the key word, not design. They will build structures, and must therefore understand the load (forces) and behavior (reaction) of structures under loads. Statics introduces students to problem solving tools and methodologies (e.g., free-body diagrams, component vectors, etc.) that form the basis for other more complex structural behavior problems. Unfortunately, the traditional lecture-based statics course is often a challenge to students (Lesko et al., 1999). This is evidenced through lower course grades, higher student frustration levels, and frequent repeats that cause students to slip behind in their graduation requirements (Kim et al., 2007).

Instructors at several other institutions have encountered similar scenarios. Previous studies examining ways to improve student comprehension in statics courses focus either on enhancing the instructional feedback received during the actual class period (Dollár and Steif, 2004) or on involving students in more experiential ("active," or hands-on) problem solving activities (Kim et al., 2007; Lesko et al., 1999; Mehta and Kou, 2005; O'Neill et al., 2007). In the first scenario, students use logic and intuition to solve problems without focusing on the actual mathematical equations used to solve specific answers. This method of instruction forces students to concentrate on the physical constraints of the problem and less on "cranking" through formulas to reach a numeric solution. This approach was similarly proposed in J.E. Gordon's book, *Structures: or Why Things Don't Fall Down* (1978), which provides a qualitative approach to statics. In the second scenario, models and physical representations of traditional statics problems are incorporated into lab sections of the conventional statics course. Using this approach, an instructor relies on the student's ability to learn through experience, similar to the experiential learning philosophies described by Dewey, Lewin, Piaget, Kolb, and others (as is reviewed in the next section).

The purpose of this study is to review developments within the experiential learning pedagogy by examining several of its key proponents, to incorporate and improve some of those developments into a construction management statics class, and then to assess the improvement of student learning over a more traditional lecture format. The authors describe their efforts at devising in-class models to enhance the experiential learning opportunities in the statics classroom.

Experiential Learning

The earliest writings on the importance of experience in education can be traced to approximately 450 B.C. when Confucius is credited with saying, "Tell me, and I will forget; show me, and I may remember; involve me, and I will understand." Yet, experiential learning, as a mainstream approach for teaching, has only found relatively recent acceptance as a widespread educational vehicle. Its foundations as a pedagogical form were not established until the 20th century, with prevalent acceptance occurring in the 1960's.

Philosophical Beginnings

John Dewey (1859-1952) is often recognized as the leading foundational figure among the early experiential learning philosophers. Dewey based much of his thought on the work of Francis Bacon (circa 1605), who linked discovery of knowledge with experience (Bacon used the term "experiments"). Dewey believed, in agreement with Bacon, that learning comes from a human being's basic inherent curiosity. In other words, humans have a natural ability to test ideas, beliefs, and theories from real life experiences, in the real world. Dewey called this "Learning from Experience." His pedagogy included a created microcosm of actual society where students actively participated in their assumed occupations; believing that the learning environment is a form of real community life, of real experiences, real attitudes, and real values (Dewey, 1897).

Kurt Lewin (1890-1947) and Jean Piaget (1896-1980) furthered the understanding and application of experiential learning in parallel paths to that of Dewey during the middle part of the 20th century. Lewin focused on the interaction of an individual's "life space" with personal experiences. While he did not use the word "experiential," he nonetheless believed that the development of an individual occurs when their "life space" has a "boundary zone" experience with external stimuli. To Lewin, it was not merely the experience that caused change in an individual's "life space," but the acceptance (internalization) of external stimuli.

Piaget's studies on how children learned revealed similar conclusions; however, the importance of the experience was only one part of his theory towards how individuals learn. To him, personal knowledge grew in "a progressive construction of logically embedded structures superseding one another by a process of inclusion of lower less powerful logical means into higher and more powerful ones up to adulthood (Jean Piaget Society, 2000)." Piaget is credited with formalizing this concept into what is currently viewed as constructivism – a theory by which cognitive development is based upon the internalization of external experiences.

Kolb and Fry (1975) expanded constructivism in the latter half of the 20th century in their publication "The Experiential Learning Model" where they explain their theory on adult learning. In this model, learning is a continuous spiral of four steps including: concrete experience, observation and reflection, forming abstract concepts, and testing in new situations. Entry into the learning spiral can occur at any one of the four steps; however, Kolb and Fry suggest that the learning spiral often begins when someone has an experience (step 1) and the results of that experience are observed (step 2), and found, upon further reflection, that their understanding is expanded and a new concept has formed (step 3). To generalize from this experience, the individual will test the new concept (step 4) over a range of circumstances. The results of this testing produce concrete experience and therefore the cycle of the spiral can be repeated. So, as in other constructivist theories, the learner gains new knowledge from active involvement.

Higher Education and Experiential Learning

In the 1960's, increasing need for more relevant curriculum caused colleges and universities to look at different educational philosophies. However, some 30 years later, Wankat and Oreovicz (1993) found that "new professors are superbly trained in content, but often have very little idea about how students learn." Modern educators, such as L. Dee Fink recommend that educators move from the view that students are passive, "sponge-like" creature absorbing the expositions of the professorate, to the view that students are active learners requiring the instructor to create "significant" learning experiences (Fink, 2003).

Outside the classroom, possibly the best indicator of the acceptance of experiential learning is the proliferation of cooperative education, called "co-op," throughout the United States. The movement began with Herman Schneider (1872-1939) while at Lehigh University at the beginning of the 20th Century. Schneider, an engineer, architect, and educator, concluded that the traditional classroom was insufficient for technical students (Smollins, 1999). Schneider observed that several of the more successful Lehigh graduates had worked to earn money prior to graduation. Gathering data through interviews of employers and graduates, he devised the framework for cooperative education.

In 1909, seeing the potential of co-op education, Northeastern University began using co-op in their engineering program, becoming only the second institution to do so in this country. By 1919, Antioch College had adapted the co-op practices to their liberal arts curricula, whereby many called co-op the "Antioch Plan." By 1946, 29 co-op programs existed, and by 1970, about 200 academic institutions used co-op education, in one form or another. In 2007, the World

Association for Cooperative Education (WACE) boasted a membership of over 2,000 individuals from 43 different countries.

Experiential Learning in a Statics Classroom

Specifically in statics, the need to create "significant" learning experiences is well documented. During the past 10-15 years, several initiatives, including those by the National Science Foundation (NSF), have been undertaken to improve overall student learning in the classroom.

Student- versus Teacher-centered Instruction

Many educational authorities cite the transformation of classroom instruction from a teacher-centered to a student-centered approach as one of the most important factors in obtaining educational improvement in undergraduate education (National Science Foundation, 1995). Earlier research by Halloun and Hestenes (1985) concluded that students' prior misconceptions about physical phenomena greatly influence what they learn in a physics course. Their approach to overcome prior misconceptions was to use student/teacher discourse to reveal and correct those obstacles to learning.

In contrast, Dollár and Steif (2002) argue for a more student-centered approach to uncover and reduce misconceptions that hinder learning basic principles of statics. Their approach mainly involved students "working in groups" and providing "hands-on activities in which they can discover principles on their own." The purpose of group work was for students to discuss and justify their understanding of statics with each other, thereby confronting and correcting misconceptions among themselves.

Student Learning Preferences

Other research suggests that the change from an instructor-centered to a more student-centered instructional approach has additional benefits. Based upon work by Felder (1993) and Kresta (1998), it has been found that there is an engineering preference for sensory information, and within this category an overwhelming preference for visual learning. As such, several educators have constructed and used physical models in the statics classroom. Most claim that students understand statics better when physical models are used compared to a traditional lecture-based statics course.

Bernold et al. (2000) used "hands-on experimentation" and "hands-on model building" as part of "the holistic teaching of statics." An example of experimentation employed sand as a pressure source to load retaining walls of various designs. Students also built a wooden model of a roof/truss structure as a semester project to provide "another opportunity for the students to 'feel' statics." Kim et al. (2007) built several mechanical devices that simulated structures and loading from textbook problems in statics. The devices incorporated transducers so that the load transfer to various parts of the structures could be monitored by students through a computer interface. The purpose of the device was to enhance students' understanding of force vectors. O'Neill et al. (2007) also built devices that simulated textbook problems in statics. However, spring scales were used instead of transducers. The students used these devices during the lab section of a lab/lecture format statics course.

While there has been more research within the engineering realm, some construction management programs have adopted similar teaching strategies within their program. Lesko et al. (1999) developed a set of experiments consisting of physical models that supported basic statics concepts taught in the classroom. They emphasized that their models were built on the scale of feet and pounds to allow “the students to develop a physical feel for the intensity and direction of loads.” Following these examples, the authors of this paper present a study on ways to increase experiential learning in the statics classroom to improve student learning.

Incorporating Physical Models into the Statics Curriculum

The statics course under evaluation for this study is a non-calculus-based curriculum taught to non-engineering students, most of who are in a construction management degree program. The topical sequence of the course and corresponding physical models are given in Table 1 below. A detailed description of each of those models is given in the following section entitled “Descriptions, Fabrication techniques, and Materials Lists”.

Table 1

List of physical models by topic in a statics course

Topics	**Physical Model**
01. Fundamental Terms	
02a. Forces 02b. Orthogonal Forces	Models 1a and 1b – Forces and Vectors
03. Coplanar Systems	Model 2 – Coplanar and Concurrent Forces
04. Moments	Model 3 – Moments
05. Equilibrium & FBD	Model 4 – Equilibrium & Free Body Diagram
06. Method of Joints	Model 5 – Plane truss
07. Method of Sections	
08. Method of Frames	
09. Beam Diagramming	Model 6 – Bending Model 7 – Shear
10. Stress and Strain	
11. Properties of Material	
12. Simple Stress Design	
13. Geometric Properties	
14. Bending Stress	Model 8 – Transverse Shear Stress

Consistent with the findings of other educators, for example Brown and Crowder (2000) and Halloun and Hestenes (1985), the instructor found students in the statics course during this study had both misconceptions about forces and difficulties with problem solving. The misconceptions included: the tension in a member equals the sum of the forces at each end, stress must be positive, passive forces in a member do not exist, and the source of a force must be a living being. The difficulties included: solving conceptual problems, visualizing a problem from a description, visualizing three-dimensional problems, and understanding the application of Newton's laws.

This study assumed that construction management students prefer "tactile" learning experience (versus a visual learning experience preference of engineers). To provide that experience, the instructor incorporated physical models into the classroom experience. Each of the physical models, shown or illustrated below, is relatively simple to construct from common material of construction available from a local hardware store. The expense of these materials is much less than a $1000 per model; some cost only few dollars. The scales are the most expensive single item in the list; the portable stand is the most expensive device.

The present paper describes physical models that also have some advantages relative to models found in the above references. The materials used here are mostly common construction materials with which students have encountered at actual construction sites. This familiarity, along with the large size of the component materials, enables the students to directly see the response (displacement) of the material under load whereas prior approaches are mostly limited to monitoring the applied and transmitted loads in structures.

Model Descriptions, Fabrication Techniques, and Materials Lists

Portable Stand

Because statics is taught in many classrooms, the demonstrations must be easy to move in and out of the classroom, and around the building. A portable stand (see Figure 1) capable of holding the weights and moments induced by the demonstrations is not a simple project, but one that can be built with simple tools and connectors. We chose to weld the steel tubing together, but the stand's connections could be bolted.

The stand is a few hundred pounds in weight, but manageably portable on casters. Horizontal platforms built at the bottom and on each side of the vertical component of the stand provide stability for the stand during demonstrations and movement. These platforms are also used to carry equipment and models.

1. Plywood: 3 – 3/8" x 4' x 8'
2. Steel Square Tubing: 1" x 60' (welded)
3. White paint (for plywood)
4. Black paint (for steel tubing)
5. Casters: 4
6. Miscellaneous hardware (bolts, nuts, washers, etc.)
7. Lumber: 2 - 2" x 4" x 8'
8. Eyehooks: 2

9. Perforated Steel Angle: 1 – 1-½” x 1-½” x 6’

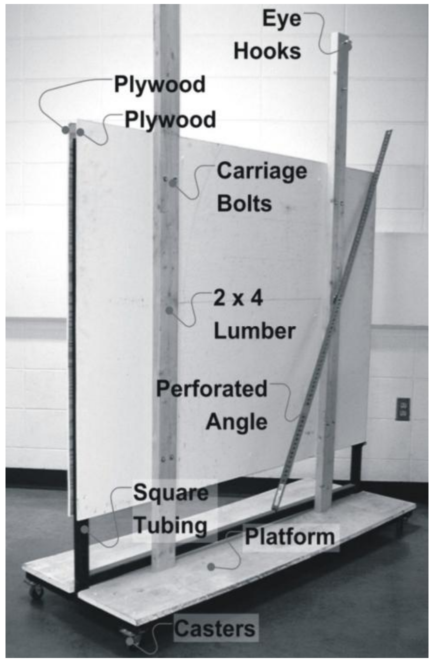

Figure 1: Portable Stand.

Model 1a- Forces and Vectors

This model, shown in Figure 2, is designed to illustrate that the forces at the ends of a member in tension do not add together become the internal tensile force in the member. The demonstration is typically conducted using two students, selected from the classroom and asked to pull a 10-pound load on the scale. The demonstration begins with one student and the instructor and one scale, pulling 10 pounds. A second student is added and a second scale, again pulling 10 pounds; and finally the third scale is added. Of course, each and every scale shows 10-pounds of load, which surprises many students. However, many students go back to this demonstration throughout the course of the semester to resolve misconceptions. Basic components are:

1. Straps: 5 – ½” x 6’ with Swiveling Self-locking Hooks
2. Digital Scales with S-hook and Carabiner: 3 – Pelouze Model #7750 (50-lb capacity)

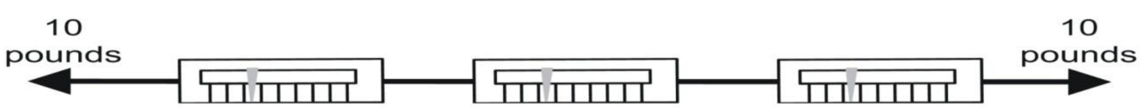

Figure 2: Model 1a – Forces and Vectors.

Model 1b- Forces and Vectors

This demonstration, illustrated below in Figure 3, shows that the forces in the horizontal and vertical components of a force match mathematically determined quantities. This can be an epiphany for many students, for what seems to be the first time, exposed to a “real” and practical application of trigonometry. The basic components are:

1. Portable Stand
2. Weights: 1 – 10 pounds
3. Straps: 5 – ½” x 6’ with Swiveling Self-locking Hooks
4. Digital Scales with S-hook and Carabiner: 3 – Pelouze Model #7750 (50-lb capacity)
5. Steel Carabiners: 4 – ¼” diameter

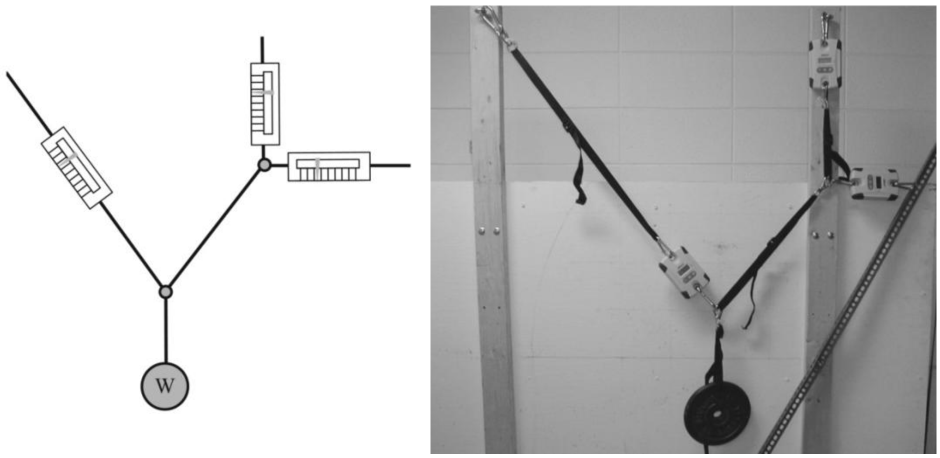

Figure 3: Model 1b – Forces and Vectors.

Model 2 – Coplanar and Concurrent Forces

This demonstration, pictured in Figure 4, is used to illustrate several concepts, including solving a force triangle, resolving components, and orthogonal vector addition. The basic components are:

1. Portable Stand
2. Weights: 1 – 10 pounds
3. Straps: 3 – ½” x 6’ with Swiveling Self-locking Hooks (8 count)
4. Digital Scales with S-hook and Carabiner: 1 – Pelouze Model #7750 (50-lb capacity)
5. Steel Carabiners: 4 – ¼” diameter

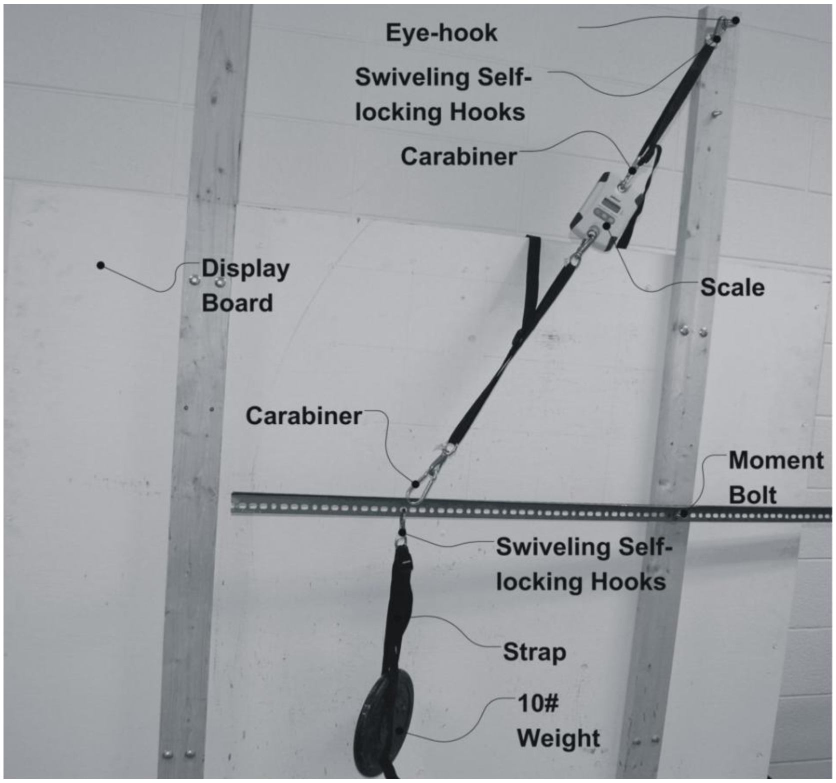

Figure 4: Model 2 – Coplanar and Concurrent Forces.

Model 3 – Moments

Model 3 uses Model 2 without the diagonal straps. Many students are familiar with the concept of torque using a torque wrench, which this demonstration exploits.

The torque wrench is placed on the bolt located at the middle of the angle (labeled "Moment Bolt" in Figure 4). Students are asked to hold and read the torque wrench as the load is applied at varying distances from the bolt. The instructor places the value read along with the force and distance in a table on the board for the students to see. The mathematical quantities of moment (force times distance) are easily demonstrated by this model. The basic components are:

1. Portable Stand
2. Weights: 1 – 10 pounds
3. Straps: 1 – ½" x 6' with Swiveling Self-locking Hooks
4. Torque Wrench

Model 4 – Equilibrium and Free Body Diagrams

Model 4, shown in Figure 5 is the most complex of the vector statics models. It demonstrates both the concepts of Newton's laws and free body diagrams (FBD). The instructor illustrates the physical model on the board using a graphical free-body diagramming model. This model can be used to illustrate end conditions of the FBD. The model also illustrates static equilibrium and force components. The basic components are:

1. Portable Stand
2. 1 – 2” x 4” x 4’ with 8-Eyehooks
3. Weights: 2 – 10 pounds
4. Straps: 4 – ½” x 6’ with Swiveling Self-locking Hooks (8 count)
5. Digital Scales with S-hook and Carabiner: 3 – Pelouze Model #7750 (50-lb capacity)
6. Steel Carabiners: 4

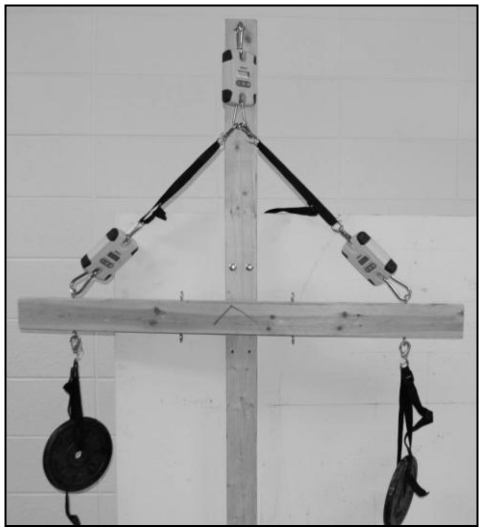

Figure 5: Model 4 – Equilibrium and FBD.

Model 5 – Plane Truss

Load tracing is a difficult concept for students to grasp. Trusses are a very good tool to illustrate that concept; however, students struggle to visualize how forces “flow” through a truss. Figure 6 shows a demonstration that provides a physical model of the forces in a truss. This truss, commonly used in textbooks and examinations, is relatively easy to illustrate on the board with FBDs. The basic components are:

1. Portable Stand
2. Lumber:
    a. Bottom Cord: 2 – 2” x 4” x 4’ with Eyehooks
    b. Vertical Cord: 1 – 2” x 4” x 24” with 2-Eyehooks
3. Weights: 1 – 10 pounds
4. Straps: 4 – ½” x 6’ with 8 Swiveling Self-locking Hooks
5. Digital Scales with S-hook and Carabiner: 3 – Pelouze Model #7750 (50-lb capacity)
6. Steel Carabiners: 4

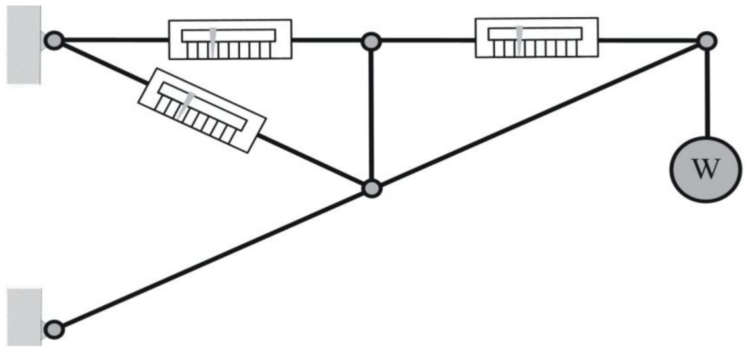

Figure 6: Model 5 – Plane Truss.

Models 6 - Models for Bending Stress

To assist students with visualizing internal forces and stresses in a beam, three models are used. The first one, shown in Figure 7, demonstrates bending deformation and bending stress distribution. Students can usually understand that the bottom of a beam is in tension and the top in compression, but fail to visualize the distribution of that stress over the profile of the beam. The basic components are:

1. “Styrofoam” block: 1 – 7” x 4’ x 24”
2. Vertical cuts in Beam from top and bottom, staggered to the neutral axis

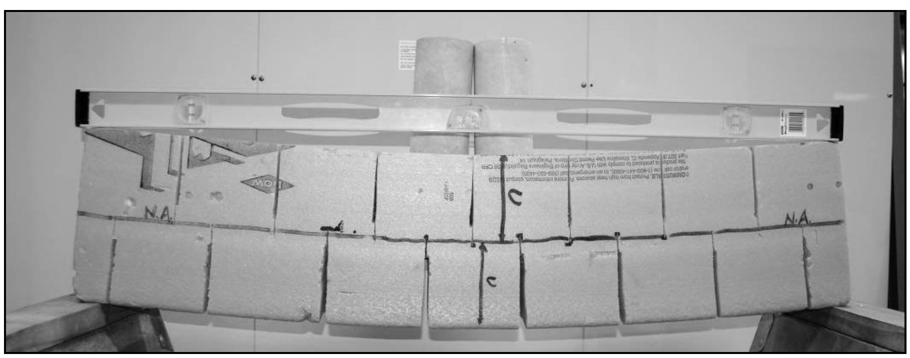

Figure 7: Model 6 – Models for Bending Stress.

Model 7 - Transverse Shear Model

Transverse shear is a relatively simple concept for students to grasp. However, student understanding of shear failure is enhanced with this demonstration, shown in Figure 8, by physically modeling vertical shear planes. The basic components are:

1. “Styrofoam” bricks: 12 – 4” x 3” x 8”
2. Rubber band and clips

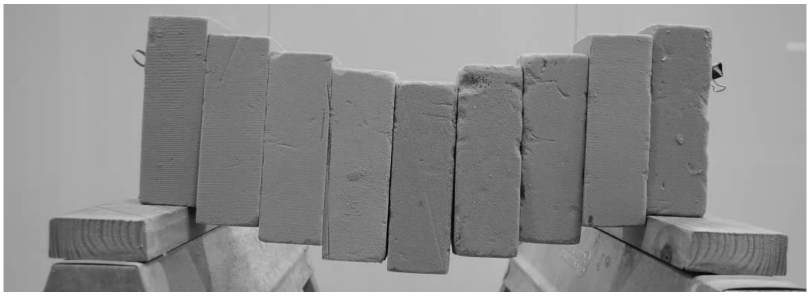

Figure 8: Model 7 – Transverse Shear Model.

Model 8 - Longitudinal Shear Model

Of the three stresses induced by bending, longitudinal stress is the most difficult for students to grasp, and for instructors to illustrate. The model, shown in Figures 9 through 11, illustrates horizontal forces in a beam; helping students visualize horizontal sliding, forces, and stresses. A telephone book or a ream of paper can also help students visualize the sliding of thin sheets at a smaller scale. The model can also help to illustrate the "statical moment of area", Q in the bending shear stress equation, by turning the model to show the end view as shown in Figure 11. The basic components are:

1. "Styrofoam" sheets: 5 – ¾" x 4' x 24"
2. String (not shown) which ties the sheets together

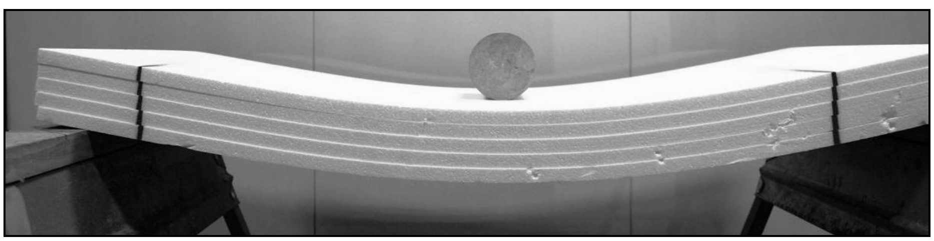

Figure 9: Model 8 – Longitudinal Shear Model.

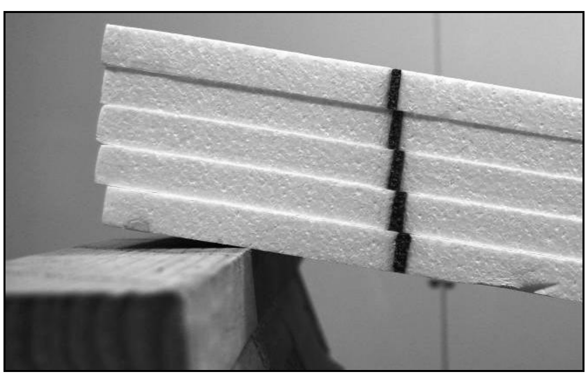

Figure 10: Close-up photo of Model 8 and horizontal sliding.

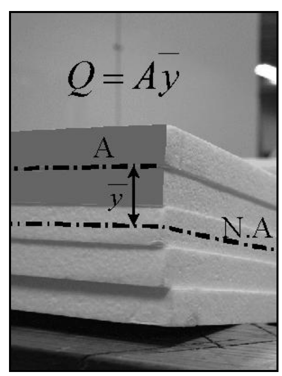

Figure 11: End View of Transverse Shear Model Showing Calculating Q.

The authors have been developing and presenting these physical models to students for several years. Through conversations with students, informal assessment had been conducted on the models' effectiveness. Generally, the students indicated that they felt these models were beneficial to them. The authors wanted to quantify the effect of the models on the attitudes of the students and to see whether or not improved attitudes corresponded to improved test scores. The following section describes an attitude survey and a corresponding test on statics principles that were demonstrated by the physical models.

Description of Test and Results

The instructor assigned students randomly to two classes. The first class received statics instruction using traditional lecturing techniques while the second class received statics instruction using both physical models and traditional lecturing techniques. Following the lecture, the instructor administered a short quiz (see Appendix) on the previous hour's material (for this study, the topic was shear and moment diagramming). The quiz also asked students to indicate "how you feel about the way class went today" on a 6 point Likert scale. The instructor also timed the quiz.

The instructor graded the quizzes from both classes at the same time using the same rubric. To check that students were randomly assigned to the class based on course grades, the average overall "Course Grade" for the two classes, 72.6% for Class 1, and 71.2% for Class 2, the instructor conducted a statistical Student *t*-test. The *t*-statistic (d.f. = 49) = 0.092, significant at $p = 0.772$, indicates random assignment. The mean values for feeling and quiz grade are shown in Figure 12 and Figure 13 below.

The instructor performed a one-way multivariate analysis of variance using "Class" as an independent variable, and overall "Course Grade" as a covariate, to determine the effect of the two different teaching approaches (traditional and model-based) on the two dependent variables, feeling and quiz grade. For this analysis, SPSS's multivariate general linear model produced an $F(2, 47) = 4.058$, significant at $p = 0.024$, indicating that we can reject the hypothesis that the variance for these two groups are the same.

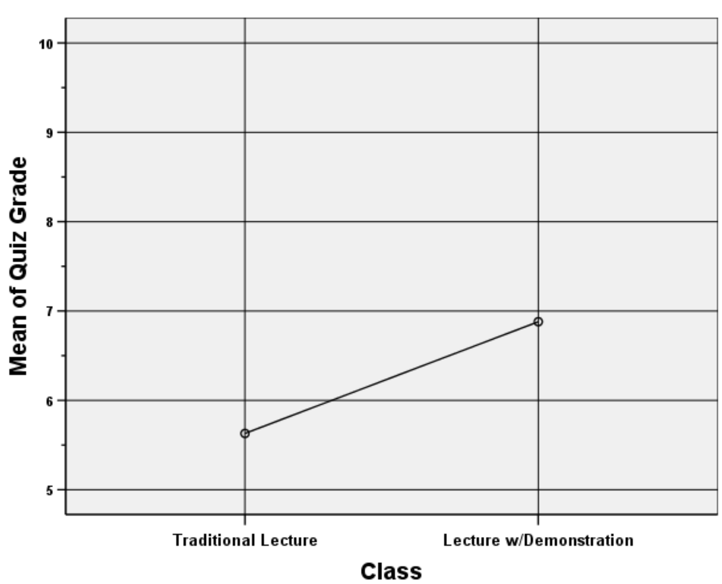

Figure 12: Mean of Quiz Grade versus Class.

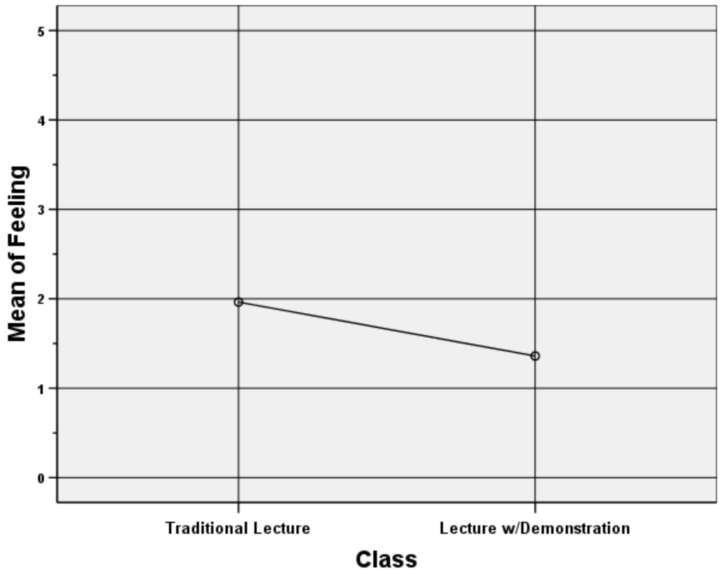

Figure 13: Mean of Feeling versus Class.

The instructor followed up the multivariate test with an analysis of variance on each dependent variable (feeling and quiz grade). Using Bonferroni method to control for Type I error, the feeling scores tested at $F(1, 48) = 6.816$, significant at $p = 0.012$, and the quiz scores tested at $F(1, 48) = 4.137$, significant at $p = 0.047$. These results show that the teaching strategies affect the performance of the feeling scores more strongly than the quiz scores. Both scores show statistically significant improvement using the demonstrations during the lecture.

Discussion and Conclusion

Based upon the philosophical background of experiential learning, this paper detailed an approach to introduce large-scale, in-class models into the statics curriculum to facilitate undergraduate student learning and comprehension through hands-on participation. This approach provides a well-grounded, experiential understanding of the behavior of structures under load; a primary learning objective for instructors who teach statics courses.

Regardless of the discipline teaching statics, this study found that matching the students' learning preferences with significant learning experiences improves the foundational knowledge statics provides for solving more complex structural behavior problems. Initial findings from the on-going research study indicate that both quiz scores and students' feelings towards lecture material increased when physical models were used in class. Initial findings, coupled with the authors' experiences, show that students who fail to adequately learn these fundamental concepts can encounter needlessly lower grades and higher frustration levels.

While there has been significantly similar work within the engineering curriculum, there has been little work done with construction management students. In particular, there is a direct need to understand the learning preference of construction management students to ensure the classroom instruction style matches their preferences. The authors are encouraged by the students' preference for physical models and plan to further study and improve the effectiveness of those models.

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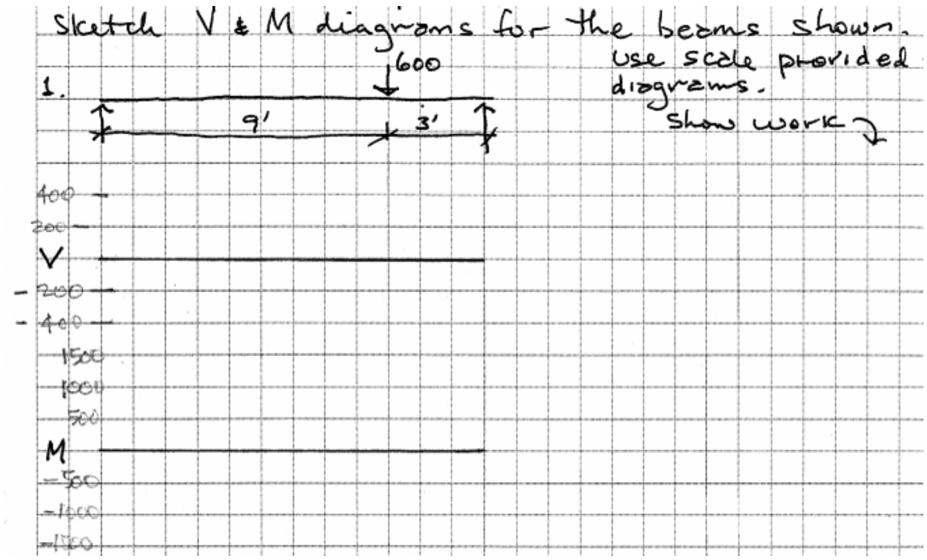
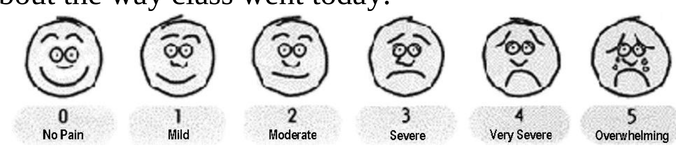
APPENDIX

In-class Quiz

NAME: ______________________________________



Circle how you feel about the way class went today:



Source: Lawson (2006).