Hands-on-Statics Integration into an Engineering Mechanics-Statics Course: Development and Scaling

Jack Lesko[A], Jack Duke[A], Seigfried Holzer[B], Flynn Auchey[C]
[A]Department of Engineering Science & Mechanics
[B]Via Department of Civil & Environmental Engineering
[C]Department of Building Construction
Virginia Tech
Blacksburg, Virginia 24061

Abstract

Trial efforts to incorporate hands on learning experiences into the engineering mechanics-statics course have been developed and scaled in an effort to bring these experiences to all sections of engineering Statics taught at Virginia Tech. During the fall of 1997 a set of experiments were developed to assist in the comprehension of mechanics of statics principles by providing concrete experiences. Hands-on-exercises were developed to support the concepts of force components, vectors, free body diagrams, moments, two and multi-force members, plane trusses, frames and machines, and internal forces and moments in beams.

Introduction

"Engineering is a fundamental human process"[1]. One has only to watch a child conceive a solution to reaching a treat initially placed out of reach to support Petroski's claim (e.g. a cookie on a table too high for the child). We all know that eventually the child will seek a chair or stool and climb to retrieve the cookie. Although this is a crude demonstration of engineering in the formal sense, it does meet with the goal of engineering.

In a more conventional sense, the discipline of engineering represents a well-defined community and has been formalized through design principles based on physical laws. It is engineering education that helps to define this community and the body of knowledge that allows one to engineer from a basis of credibility. Yet the skills and perspective of the engineer are not that far removed from the skilled craftspersons who created machines and devices through out history. While their ability to conceive and create is innate, their proficiency comes from other sources in the absence of formal training. Where then did the skilled craftsperson find the basis to create and build? One can certainly identify the process of apprenticeship process in this regard. Here the individual is trained by doing. Experiences shape the "education" of the individual and practice forms the basis though which skills are transferred and a community defined.

Thus, it is our claim that though the process of tangible and physical experiences, the learning process is in part carried out. This perspective is possibly best demonstrated in fuller context by Kolb [2]. "Learning is a process whereby knowledge is created through the transformation of experience"[2]. Within this perspective, concrete experience and experimentation form critical components of the learning process as illustrated in Figure 1.

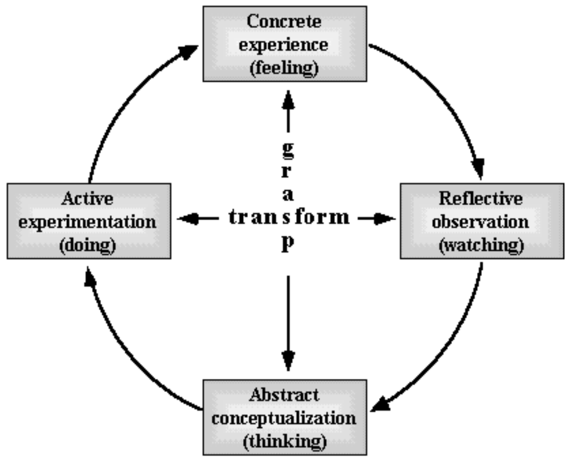

Figure 1. Experiential Learning Model [2]

Furthermore, these components are only part of an integral representation of the learning process. This process suggests two opposite modes of grasping, directly through the senses (concrete experience) or indirectly in symbolic form (abstract conceptualization). Similarly there are two distinct ways of transforming experience, by reflection or action. The complete process is a four-stage cycle of four adaptive learning modes. The active involvement of students through all four learning modes helps develop higher-order skills [2, 3]. Traditional lecture tends to favor the reflective observation and the abstract conceptualization. Laboratories have in many cases presented a means to introduce concrete experience into the learning process. Yet, such efforts are limited to particular classes and typically not available in the early engineering courses.

The motivation for a hands-on course for the engineering mechanics course was born from this perspective. Trial efforts to incorporate hands-on learning experiences into the engineering mechanics-statics course have been developed and scaled in with the overall goal of bringing these experiences to all sections of engineering Statics taught at Virginia Tech. This paper will detail these efforts and an attempt to quantify their effectiveness.

Development of Hands-on-Statics Exercises

Approach

Hands-on-exercises were developed to support the concepts of force components, vectors, free body diagrams, moments, two and multi-force members, plane trusses, frames and machines, and internal forces and moments in beams. These exercises are design to precede the lecture material so as to provide an inductive approach to the concepts.

Working with physical models on the scale of feet and pounds allows the students to develop a physical feel for the intensity and direction of loads. The exercises emphasize connecting the physical reality of the concepts under study. In most cases the experiments were geared more towards discovery than rout sequential steps to facilitate exploration. This is not to say that this was always achieved in practice; a certain amount of step wise progression was needed to ensure progress in the desired direction.

While the exercises were intended to facilitate a physical understanding for the concepts presented in statics, they also presented an opportunity to foster cooperative and team work oriented learning. Much of the work can be done individually but lends itself well to think-pair-share (TPS) [4, 5] and variations of pair activities [6]. Collaborative exercises are almost always necessary in carrying out the exercises through teaming on loading/actuating and measuring features within the experiments.

This first hands-on course is part of a larger effort to develop a set of hands-on courses to reinforce the principles of engineering statics (undertaken in 1997-98) and mechanics of deformable bodies (to be completed in 1998-99). The final phase of the program (to be undertaken in 1999-2000) will vertically integrate these two one-hour courses with a design project that will benefit the community (i.e. a footbridge or children's play equipment). In addition, the three courses, designed for engineers, architects and building constructions majors, provide a vehicle to integrate these disciplines allowing them how to learn, work and design together as they would in the real world.

Examples of Hands-on Exercises in Statics

What follows is a brief description of four of the experiments developed for the hands-on statics activities. Specific details are not included due to the limitation of document length but can be had though contact with the authors.

Vector Components and Free Body Diagrams: Clearly one of the more difficult concepts for the Static student is that of vector components and free body diagrams. This experiment was conceived to assist the student in identifying the components of a force and where to place the vector.

A weight is supported by two ropes at equal angles to the horizontal as shown in Figure 2. The weight is supported on the rope via a pulley at the apex of the connection. The students are asked initially, with no scales present, to draw free body diagrams of the weight, the pulley and the rope terminations above. In the process they are given the opportunity to experiment with the systems and discuss the placement and direction of forces. A scale is added in line with one of the ropes to assess the force as illustrated in the left-hand arm of Figure 2. They are then given the opportunity to describe the components of the force and then measure them as depicted in the right-hand arm of Figure 2.

Plane Truss Experiment: Plane trusses present some problems to the Statics student simply because they are not given access to the physical realities of the structure. This simple experiment reinforces the ideas of zero force member and determination of the member forces. With ropes as a convenient component of this truss, the concept of members in tension and compression can also be made. Further work is being carried on this experiment to include devices that sense and readout compression force economically. The experience also provides an opportunity to discuss forces in pinned joints.

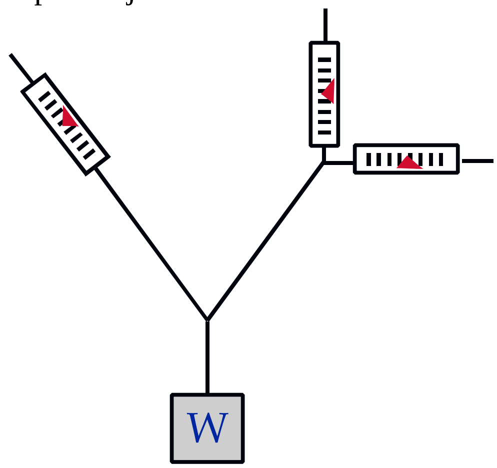

Figure 2. Hanging weight experiment

Frames and Machines: The distinctions between frames and machines and plane trusses present an opportunity to emphasize their differences and features of connections. Comparing the plane truss and the frame shown in Figure 4 provides a simple and convenient means to point out features of two force and multi-force members, connection forces and the direction of forces. What is possibly most helpful to the students is the physical feel that can be established through exploration with the scales in measuring connection forces and directions.

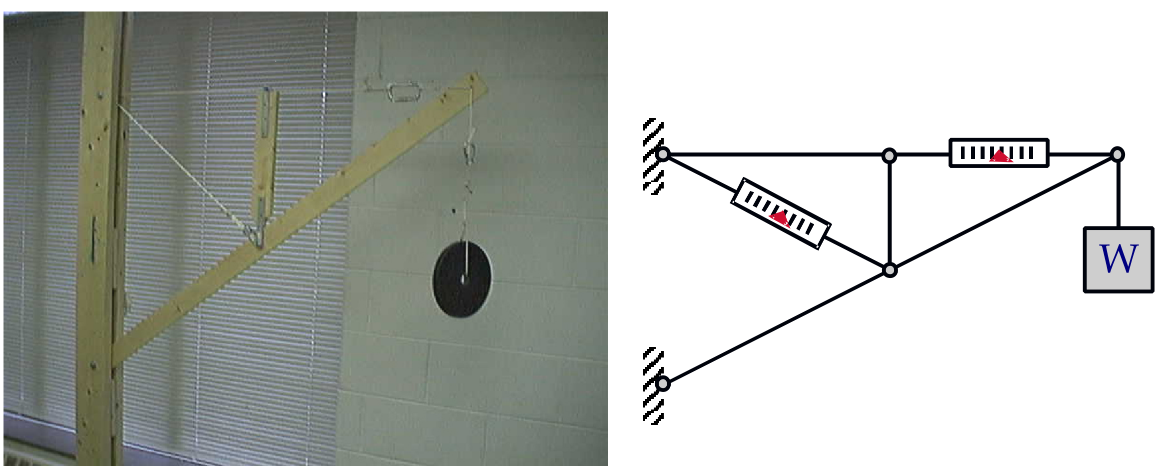

Figure 3. Plane truss experiment

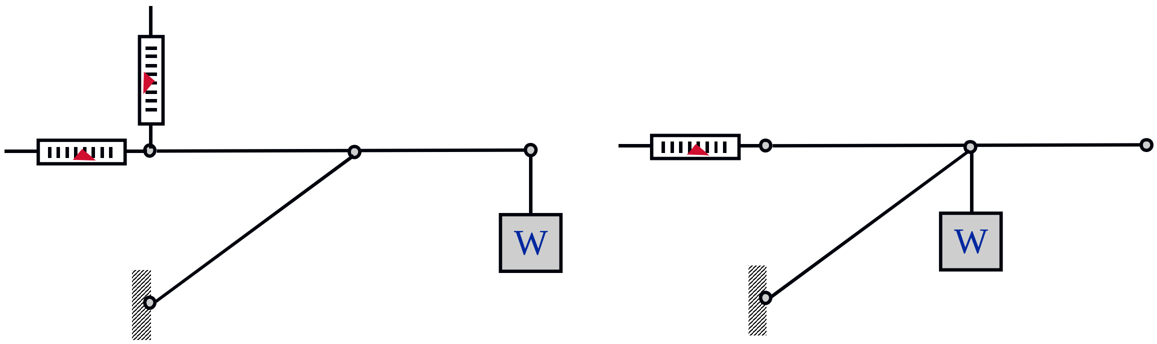

Figure 4. Plane truss vs. frame and machine experiment

Internal Forces & Moments in Beams: Developing an experiment for internal forces and moments in beams presented a considerable problem. Yet it is a feature that was deemed important due to the difficulties students would bring the mechanics of deformable bodies course. The initial experiment developed demonstrates a number of features that could also be helpful in the subsequent classes; i.e. deflection of beams. The four point bending experiment illustrated in Figure 5 incorporates 1-inch OD PVC pipe as the beam. An additional section of pipe, half the span, is fitted with a device that allows the student to produce a couple at mid span. Upon loading this half-span section the student becomes aware of the absence of shear in the constant moment region when matching the deflection and curvature of the loaded full span beam which is placed in back. This experiment has shown to be very successful yet only covers one in a many number of possible conditions. Future efforts will establish other more flexible means to demonstrate internal forces and moments.

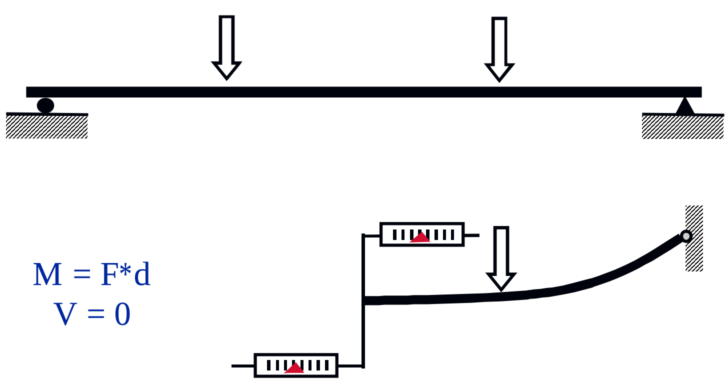

Figure 5. Beam experiment

Implementation and Scaling

A one credit hour pilot version (special study ESM 4984) of this course was offered spring 1998 in an attempt to more fully develop the concepts and the materials for this class. The response from the class of engineer and building construction students, 10 in all, was very positive. In the fall of 1998 one section of ESM 1004 Engineering Static (three credit hour) was taught with these concrete experiences integrated directly into the lectures. With approximately 45 students in the class, experimentation by all the students was not possible as was achieved in the spring 1998 one-hour pilot section. Space and time played a role in how the hands-on aspects were completed and contributed to the learning process as will be discussed below.

Assessment of Effectiveness

The success of this effort to scale the hands-on approach taught in the fall of 1998 ESM 1004 classes was judged based on a comparison of class performance of three sections (ranging in size from 37-35 persons) with and without the hands-on element. These three statics classes received the same lecture material, via a uniform syllabus, while one of the sections had the concrete experiences integrated into the lectures. The three sections were each taught by a different instructor. Common tests were administered, and uniformly graded, to all three sections in an effort to accurately assess the level of comprehension. To demonstrate the uniformity of the classes a Statics Readiness Test (or pre test) was administered by the Virginia Tech Engineering Science & Mechanics (ESM) department. This test attempts to define the skill level of the students about to participate in the Statics class.

Table 1. Comparison of scores with and without the hands-on element of instruction for ESM 1004 Engineering Statics. The Pre Test of Statics Readiness test is based out of 25 points and the ESM 1004 tests and final exam were based on 100 points.

	Pre Test	Test 1	Test 2	Test 3	Test 4	Final Exam
With	50%	86%	53%	66%	59%	48%
Without	50%	88%	45%	63%	57%	46%

The Readiness Test suggests that the students came to the classes with very similar skill levels as summarized in Table 1. These scores were not unlike the overall average of 50% computed from the 12 sections taught the fall of 1998. Clearly there appears to be no effect on the test and exam performance when comparing classes with and without the hands on element.

Conclusions and Remarks

The authors believe that the lack of improvement observed can be accounted in the inability to have all of the students physically involved with the experiments, given the size of the sections. Given the constraints of the class size, all students were not exposed to this feature in the same way achieved in the one-hour pilot course. This simply lead to the students "watching" and not "doing" as would be the mode in a lecture dominated course. Thus the recommendation to the department will be to attempt to acquire space and class size that is conducive to carrying out a truly integrated hands-on experiences and lectures in future scaled sections of ESM 1004.

Although the results were not positive, they do speak to the appropriate scope and context in which to carry out hands-on activities. Certainly we all can agree that hands-on activities will assist in the learning process given the appropriate environment. This exercise has helped to refine that environment, understanding the important difference between watching and doing.

Acknowledgment

Funding for this work was provided by the NSF to SUCCEED (Cooperative Agreement No. EID-9109053). SUCCEED is a coalition of eight schools and colleges working to enhance engineering education.

Bibliography

1. Petroski, H., *Invention by Design: How Engineers Get From Thought to Thing*, Harvard University Press, Cambridge, Massachusetts, London, England, (1996).
2. Kolb, D., *Experiential Learning*, Prentice Hall, Englewood Cliffs, NJ (1984).
3. Wankat, P. C. and F. S. Oreovicz, *Teaching Engineering*, McGraw-Hill (1993).
4. Habel, Margaret, *CEUT Faculty Workshop*, Virginia Tech, February 10 (1996).
5. Lyman, F., "Think-Pair-Share: An Expanding Teaching Technique," MAACIE, *Cooperative News*, 1(1) (1987).
6. Holzer, Siegfried M. and Raul H. Andruet, "Learning Statics with Multimedia and Other Tools," ASEE, Seattle, WA (1998).