AC 2008-2105: LEARNING STATICS – A FOUNDATIONAL APPROACH

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Learning Statics – A Foundational Approach

Statics is a pivotal course, whose concepts serve as the building blocks for future courses in engineering, mechanics of solids and design in particular. There is a common disappointment among many educators in the students' abilities to apply the concepts to design/analyze real systems in the subsequent courses. The literature review also points to several innovative teaching pedagogies to alleviate the problems. The authors' teaching pedagogy is based on the premise that students learn more effectively when the relevance of the concepts to real world problems and a systematic improvement in their skill set is tactilely, emotionally, and rationally understood. The pedagogy uses five teaching instruments: case studies, short design examples, intelligent formulation problems, concept questions, and work sheets. The paper discusses rationale behind these instruments and its implementation with examples. The results of a student survey indicate that the five instruments had a positive influence on the learning experience.

I. Introduction

Statics, which deals with the study of systems that are in a state of rest or uniform motion, is a fundamental course. The concepts in statics serve as the building blocks for future courses in engineering, mechanics of solids in particular. However, from our experience in teaching follow-on courses to statics, mechanics of solids, machine design, aircraft structures, aerospace and mechanical engineering capstone design courses, and finite element analysis, we found two fundamental disconnects present in some of the most popular statics textbooks:

- Emphasis, perhaps overemphasis, of the role of vectors in analyzing structures. This may be attributed to a strong influence of physics in the texts. Then, the text-books in mechanics of solids do not even mention the vector concepts.
- A lack of physical feel due to emphasis on structural problems. This can be attributed to a strong civil engineering influence in the texts.

These fundamental disconnects manifest themselves as lower-than-expected abilities in the students when applying the concepts to design/analyze real systems in subsequent courses. The resulting disappointment in engineering educators is well documented and common[1,2].

II. Literature Review

Most recent efforts revamp the statics/mechanics curriculum by incorporating advances in computer/video/web technologies, affording a physical feel for the concepts, and fostering active learning. Kuznetsov[3] developed a software-based teaching aid which reinforces concepts through an iterative learning process. It was observed that the best results were obtained when students solve program-generated realistic problems immediately after the lecture using the step-by-step method. The Web-based interactive homework assignments and quizzes were developed using Mallard. The web modules provided judgment, feedback, and help at each step. Pollack[4] presents an educational intervention on a small scale case study based on conversational learning for the basic mechanics course. The concept is based on "Tell me and I forget, show me and I remember, involve me and I understand". Most students found this method of learning enjoyable. The paper provides evidence that there was an overall increase in the students' motivation to learn. Steif and Dollár[5,6,7] report the development of a web-based statics course. This commendable effort, a part of Open Learning Initiative (OLI) at Carnegie Mellon University, delivers instructional material and acts as an online tutor for students. Steif, et. al.[8] present a "body-centric talk" approach to teach and learn statics. The teaching philosophy is to induce classroom discussions about bodies and their relations to forces; the conceptual structure of Statics. Several protocols were obtained from students solving problems both before and after instruction. The paper documents the potential benefits from this approach using the protocol analysis. Steif and Dollar[9,10] provide an effective learning environment that incorporates knowledge about typical difficulties faced by students in Statics. The course material is divided into modules with clearly defined learning objectives that enabled concurrent fine grained assessment of student learning. This assessment allowed individual students to track their learning, instructors were empowered to administer targeted remedial instruction to individuals, and to discern larger patterns of challenges faced by the students. The course provided discovery based learning that integrated questions with simulations, demonstrations of procedures, and opportunities for learners to practice skills while receiving hints and feedback.

Rutz et. al.[11] show that the student performance is better in a technology enabled courses (Web-assisted/streaming media/interactive video) in comparison to a traditional instructor-led course. Several teaching instruments focused on exploiting the role of physical experience in teaching the concepts. Ji and Bell[12] argue that making abstract concepts more observable and tangible enable students to better learn them. To make concepts observable and tangible, they use three themes in their teaching: providing simple demonstration models, providing good engineering examples, and improving teaching material by including new research concepts. A good collection of the teaching material is available online[13]. Williams and Howard[14] emphasize the role of laboratory experience for a physical insight. They outline the design of a versatile and economical apparatus for both in-class and laboratory experiments in statics. O'Neill et.al[15] used "Introductory Mechanics System by PASCO Scientific of Roseville, CA" in their integrated lecture-lab format course to create an environment for active participation and reinforce the fundamental concepts. Williams II et. al[16] synergistically combines the computer simulations with the physical feel. They use a novel approach using haptic interfaces (provide force and tactile feedback from virtual models) to help students in appreciating the change in parameters by providing a physical feedback. Jong[17] successfully applies the virtual work method, which is not commonly covered in statics. Newcomer[18] developed a case-study based approach for teaching Statics that is organized around five topics: free body diagrams, equilibrium, equivalence, separation of rigid bodies, and friction. In this approach, students use a consistent method to draw free body diagrams, develop equilibrium equations, and solve the equations for unknowns. Conceptual warm-up exercises are used to assess student misconceptions in each topic and enhance their learning. Gardner and Jacobs[19] developed a structural experience for students that help them to make abstract theoretical concepts that they learn in early stages more robust. Embedded in this experience were strategies that reflected both 'good teaching' practice and relevant management strategies. The authors have developed a case study with accompanying worksheets that became the scenario for rich assessment tasks for later university theoretical work. The strategies students learned during this experience provided evidence of transferable learning generating deeper and life-long learning experience. The feedback from students indicated a worthwhile experience.

III. Teaching Pedagogy

The authors' teaching pedagogy is based on the premise that students learn more effectively if the relevance to real world problems is felt, and a systematic improvement in their skill set is seen. To address the issue of relevance, several short examples and case studies were presented which illustrate good designs that intelligently embody the concepts in statics, and engineering disasters that resulted in the loss of human lives. The other three instruments (concept questions, intelligent formulation problems, and work sheets) are targeted at improving the skill set in a noticeable fashion. The examples in this section highlight these five instruments.

3.1. Case Studies

Case studies can help us learn from the historic failures and successes, reuse the knowledge that was created before, and also, realize the intended and unintended social and economic consequences of technology. Most students comment that the "stories" were useful in remembering and recalling the concepts. Thus, they serve as excellent mental cues.

3.1.1. The Loss of the Mars Climate Orbiter

The NASA Mars Climate Orbiter, the first interplanetary weather satellite designed to orbit Mars, was launched on December 11, 1998. It was lost after its entry into Mars occultation on September 23, 1999. An investigation determined that the root cause for the failure was an improper use of units; the design teams were working with different systems of units. While the interface documentation required the thruster performance data to be in the SI system, one of the teams used the FPS system and failed to convert them. As a result, the $125 million orbiter was lost. As Dr. Edward Stone, director of the Jet Propulsion Laboratory, succinctly said "Our inability to recognize and correct this simple error has had major implications."

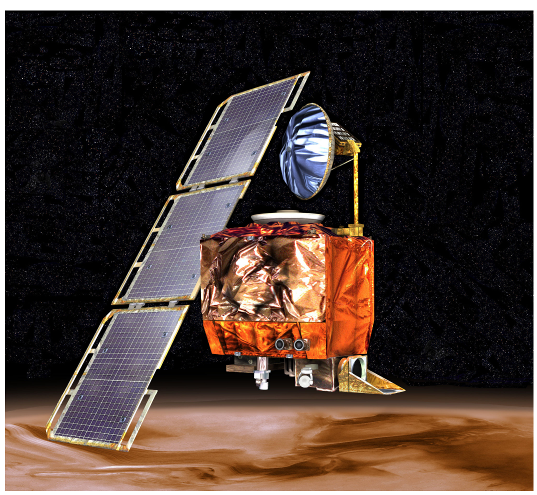


Figure 1. NASA Mars Climate Orbiter (photo courtesy of NASA)

3.1.2. Kansas City Hyatt Regency Walkway Collapse

The collapse of Kansas City Hyatt Regency Walkway illustrates the impact of simple mistakes in computing the equilibrium of a one-dimensional system. In the original design, the second and fourth floor walkways were suspended using a set of steel tie-rods as shown in fig. 2(a). During the construction stage, the design was modified to suspend the second floor from the fourth floor as shown in fig. 2(b). The nut originally designed to take the load of one floor began carrying the total load of two floors. On July 17, 1981 during a tea dance contest, the two walkways collapsed (shown in fig. 3) killing more than one hundred people.

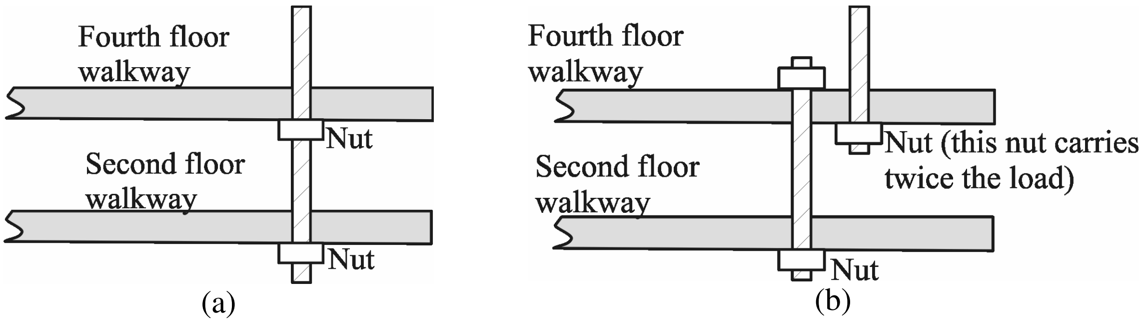


Figure 2. (a) Original design (b) modified design

Figure 3. Images of the collapsed Kansas City Hyatt Regency Walkways (Photographs taken by Dr. Lee Lowery, Jr., P.E.)[20]

3.2. Short Examples

The short examples connect the concepts to real-world applications. They enable the students to develop an appreciation for features of everyday products. The insights gained through these examples hopefully plant the seeds of reasoning that develop the student's intellectual independence. The following two examples illustrate the challenge in determining the direction of friction force. While the literature points to the difficulty in determining the magnitude of frictional force[21], this deficiency is not well-documented.

3.2.1. Friction – Lock and Latch Mechanism

Many engineering problems involve friction and determining the correct dimension and magnitude is a challenge. The following example illustrates the thought process for determining the direction. Let us consider the friction between the latch and a strike plate while closing a door. A schematic of the latch along with the strike plate is shown in fig. 4. When closing the door, the latch hits the strike plate and due to contact, a normal force comes to play and acts perpendicular to the contact surface. The frictional force should act along the surface which leads to two possible directions. As friction opposes the inward motion of the latch, the direction is as shown in fig. 5

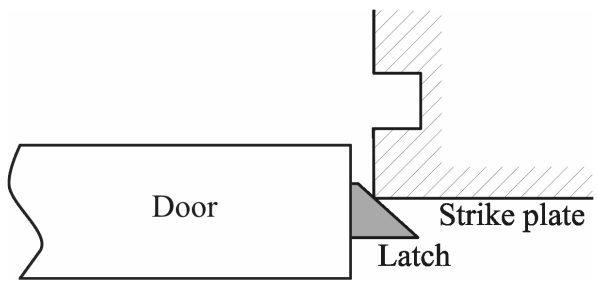


Figure 4. A schematic of latch mechanism

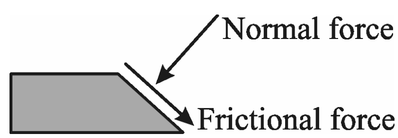


Figure 5. The free-body diagram showing the frictional force between the latch and the strike plate while closing the door

3.2.2. Friction –Wheels of a Car

Another example, a friction force pair exists between the wheels of a car and the road at the contact interface. When accelerating, the front drive wheels spin in the clockwise direction as shown in fig. 6. As the friction force opposes this spinning motion, the friction force acts in the forward direction (same direction as the motion of the car), which is counter-intuitive. The rear wheels spin and follow the motion of the car, and the friction force opposes the forward motion of the rear wheels. Therefore, it acts in the direction opposite to the motion of the car.

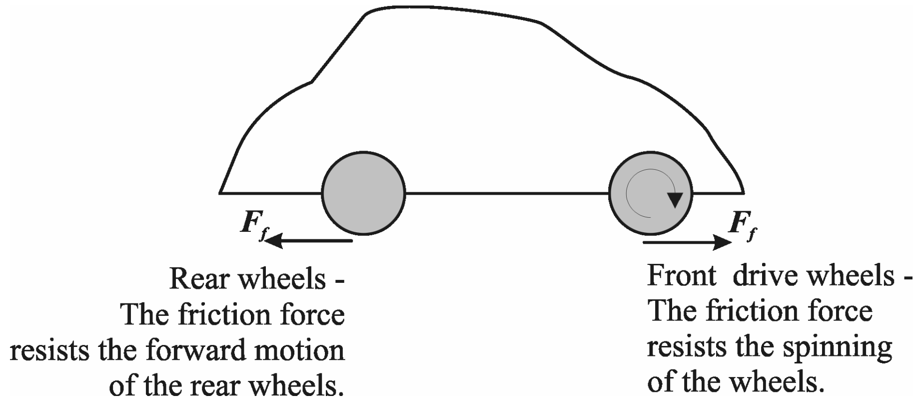


Figure 6. The friction force on the wheels of an accelerating car

3.2.3. Couple - Caster Design

An intelligent application of a couple is the design of casters in office chairs, wheel chairs, furniture, and shopping carts. A caster is designed to self-align, i.e., when a user pushes a chair, the moment of the force couple rotates the wheel in the direction of motion. To create the couple, the pivot and the reaction at the ground are offset in the caster design.

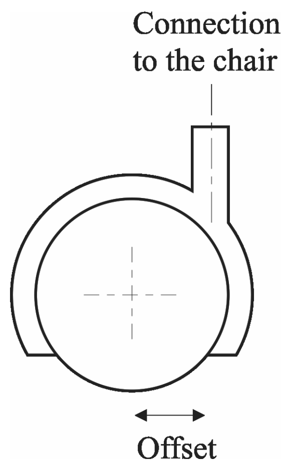


Figure 7. Caster design

3.3. Intelligent Formulation Problems

These problems are designed to nurture the ability to identify alternative approaches to formulate the problem. This enables them to get out of stuck-in-a-rut as well as verify the result in an alternative method.

3.3.1. Problem 1

Let us look at the problem of a boom supporting a 2000 lb weight at its end. The projection of its end A on the xy plane is shown in fig. 8. The boom is supported by two cables, AB and AC. The cables can only exert tensile load, whereas the boom can take loads along its axis in both directions. The students are required to determine the tension in the cables and the force carried by the boom.

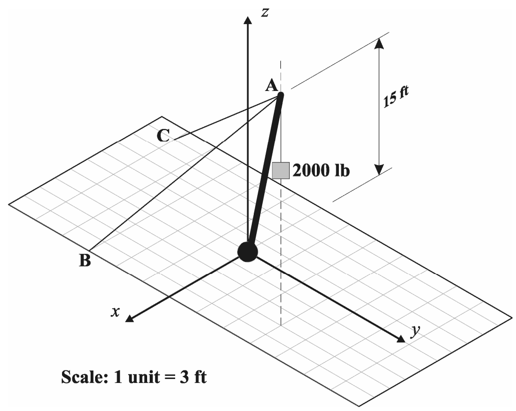


Figure 8. A boom supporting weight.

The free-body diagram for joint A shows three unknown forces (two tensions in the cable and one force in the boom). The tensions in the cable pull the joint along their length. Therefore, the arrows point toward joint B and C. On the other hand, we assumed that the boom will be in compression and, therefore, will push on joint A.

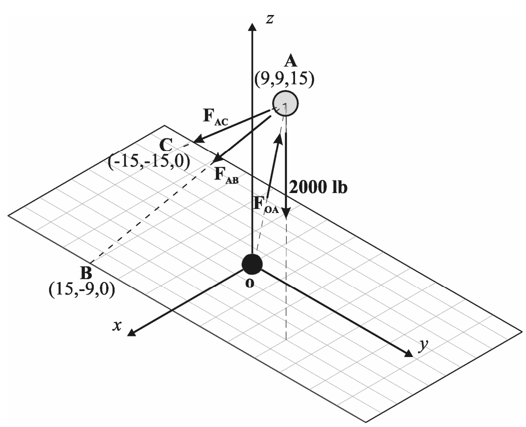


Figure 9. Forces acting at joint A.

We can determine the tension in the cables by applying the equilibrium equations to this three dimensional force equilibrium problem.

Now, if we look at the problem carefully, we can observe that all the forces except $\boldsymbol{F_{AB}}$ lie in a single plane (see fig. 10). For the out-of-plane component of the force equilibrium to be zero, this force must be equal to zero. If we intelligently pick a coordinate system, we can reformulate this problem as a two-dimensional system.

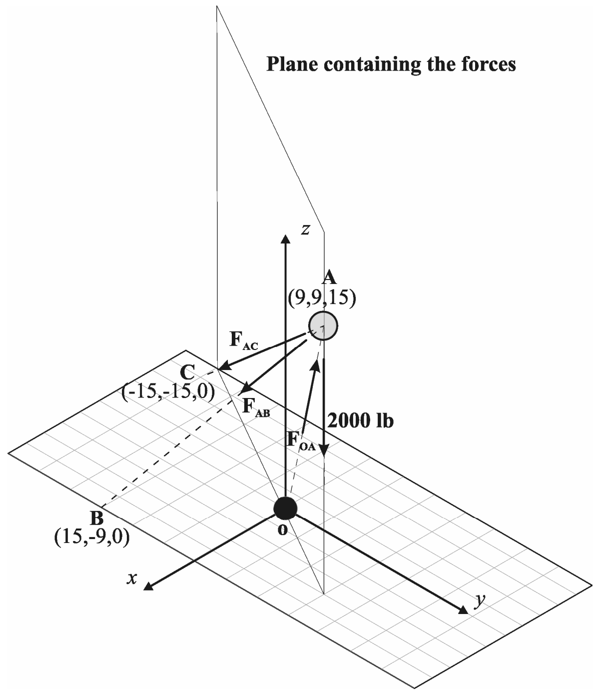


Figure 10. Two dimensional formulation of the problem.

<u>3.3.2. Problem 2</u>

After an in-depth examination, one can reformulate the following problem using symmetry in two-dimensional terms and determine the contact reaction forces. A cardboard sheet is folded to create a trihedral cavity. A golf ball is placed in the cavity. The diameter of the golf ball is 40 mm. Its mass is 45 g. Determine the reaction forces at the three points of contact.

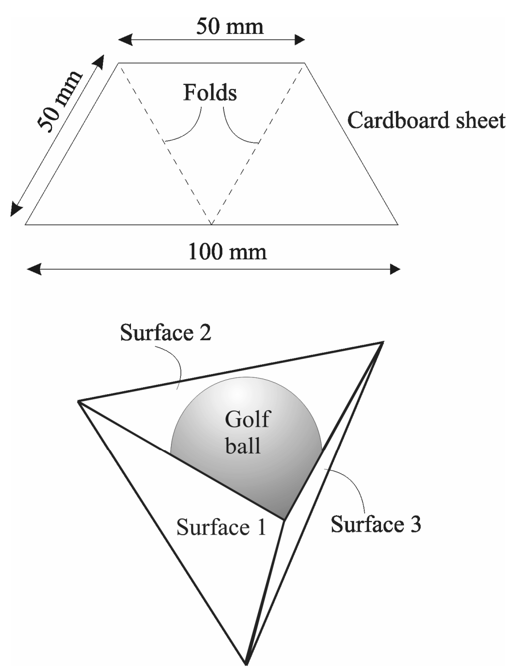


Figure 11. A golf ball in a trihedral depression.

3.4. Conceptual Questions

Conceptual understanding is critical for increasing the retention of the concepts over a long period of time, applying the appropriate concepts to the different situations, and seeing the big picture. When properly used in a course, concept questions can help to rectify misconceptions, and encourage active learning[21]. In this course, concept questions were used to promote conceptual understanding. Some conceptual questions dealing with springs are:

1. TRUE/FALSE: In a series spring arrangement, forces experienced by the individual springs are the same.

2. TRUE/FALSE: In a series spring arrangement, displacements experienced by the individual springs are the same.

3. Two springs with spring rates 10 kN/m and 20 kN/m are arranged in parallel. The effective spring rate is:
    a. less than 10 kN/m
    b. greater than 20 kN/m
    c. between 10 and 20 kN/m

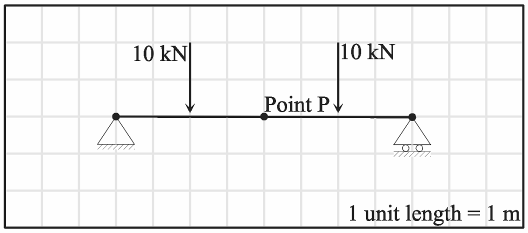
4. Two springs with spring rates 10 kN/m and 20 kN/m are arranged in series. The effective spring rate is:
    a. less than 10 kN/m
    b. greater than 20 kN/m
    c. between 10 and 20 kN/m

3.5. Worksheets

Worksheets, a standard teaching instrument for paper-based learning, are used to systematically improve the skill set. Introductory worksheets were designed to offer a large number of simple problems that focus on a specific concept. Once the student is at ease with the individual concepts, the challenge worksheets develop the strategic thinking skills. These worksheets initially assist in the strategy by decomposing the problem into discrete steps. As students gain expertise, they work independently. Worksheets offer continual feedback and gradually reinforce the physical reasoning by requiring students to think whether the results make sense at each step. A sample worksheet is shown in fig. 12.

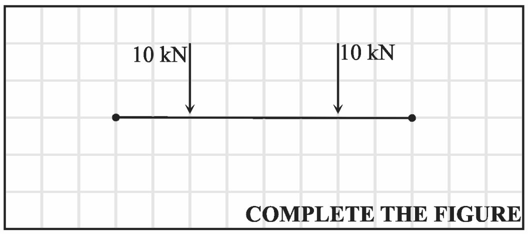
Problem 1

Determine the shear force and bending moment at Point P (midpoint).



Step I:Determine the support reactions

a. Draw the free-body diagram



b. Apply the equilibrium equations

$\Sigma F_y =$

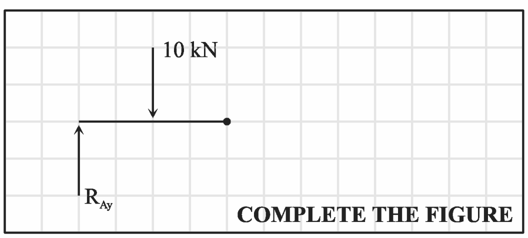
$\Sigma M =$

c. Solve for the unknown reactions

Do you think the results make sense?

By looking at the symmetry, we could have determined the reactions to be numerically equal to the assigned load.
In many cases, the symmetry helps in solving the problems by inspection.

Step II: Draw the free body diagram for the selected portion of the beam



(Rememer: In your mind, divide the beam at point P. Then, decide which portion is easy to analyze)

Step III: Determine the values of the shear force and bending moment

a. Apply the equilibrium equations

$\Sigma F_y =$

$\Sigma M =$

b. Solve for the shear force and bending moment

Does the value of the shear force make sense?

$V =$ ______

$M =$ ______

Figure 12. A sample worksheet.

IV. Conclusions

Teaching insights used in statics originated from teaching follow-on courses. An effort was made to try some of these concepts for the first time in Fall'07. Even though this material (with some errors) was being introduced for the first time, the students seemed receptive to the approach. In the Statics course, the students (n = 42) were asked to rate the effect of each teaching instrument on the learning experience using the following scale: 5: Very positive, 4: Positive, 3: Neutral, 2: Negative, and 1: Very negative. Table 1 provides the data across two sections and table 2 summarizes the results of the survey.

	Very Positive		Positive		Neutral		Negative		Very Negative	
	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)	Freq.	Freq. (%)
Case studies	11	26.19	20	47.62	10	23.81	1	2.38	0	0.00
Short examples	10	23.81	23	54.76	6	14.29	3	7.14	0	0.00
Intelligent formulation problems	5	11.90	20	47.62	15	35.71	2	4.76	0	0.00
Conceptual questions	9	21.43	19	45.24	10	23.81	2	4.76	2	4.76
Worksheets	7	16.67	16	38.10	14	33.33	3	7.14	2	4.76

Table 1. Student evaluation of the effect of the five teaching instruments on the learning experience

	Mean	Std. Dev.
Case studies	3.98	0.78
Short examples	3.95	0.82
Intelligent formulation problems	3.67	0.75
Conceptual questions	3.74	1.01
Worksheets	3.55	1.02

Table 2. Summary of the survey results

While the preliminary results and the informal feedback from the students is encouraging, plans are being made to develop these five instruments further by adding more sophisticated case studies, examples, and problems. In the forthcoming semester, it is planned to move beyond simple student surveys to more objective assessment of student achievements.

References

1. Harris, T.A., Jacobs, H.R., "On effective methods to teach mechanical design," Journal of Engineering Education, Oct., 1995, pp. 343-349.
2. Steif, P.S. and Dantzler, J.A., "A statics concept inventory: Development and psychometric analysis," Journal of Engineering Education, Oct., 2005, pp. 363-371.
3. Kuznetsov, H., 2002, "Technology-based Innovative Teaching Methods", Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
4. Pollack, M., 2005, "Basic Mechanics: Learning by Teaching – an increase in student motivation (a small scale study with Technology Education students), 35th ASEE/IEEE Frontiers in Education Conference.
5. Steif, P.S. and Dantzler, J.A., "A statics concept inventory: Development and psychometric analysis," Journal of Engineering Education, Oct., 2005, pp. 363-371.

6. Steif, P.S. and Dollár, A., 2007, "An interactive web-based statics course," Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition.
7. Steif, P.S. and Dollár, A., 2003, "A new approach to teaching and learning Statics," Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition.
8. Dollár, A. and Steif, P.S., 2003, "Learning modules for the Statics classroom," The International Journal of Engineering Education, Vol. 22(2), pp. 381-392.
9. Paul S. Steif, etal, "Work in Progress: Improving Problem Solving Performance in Statics through Body-Centric Talk", 36th ASEE/IEEE Frontiers in Education Conference, Session S2D-1, October 28 – 31, 2006, San Diego, CA.
10. Paul S. Steif, Anna Dollar, "Work in Progress: An Interactive Cognitively- Informed On-Line Statics Course", 36th ASEE/IEEE Frontiers in Education Conference, Session S2D-3, October 28 – 31, 2006, San Diego, CA.
11. Rutz, E., Eckart, R., Wade, J.E., Maltbie, C., Rafter, C., and Elkins, V., 2003, "Student performance and acceptance of instructional technology: Comparing technology-enhanced and traditional instruction for a course in statics," Journal of Engineering Education, Apr., 2003, pp. 133-140.
12. Ji, T. and Bell, A. J., 2000, "Seeing and touching structural concepts in class teaching," The Proceedings of the Conference on Civil Engineering Education in the 21st Century, Southampton, UK.
13. Seeing and touching structural concepts, http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/, last visited on January 16, 2008.
14. Williams, R. and Howard, W., 2007, "A versatile and economical apparatus for experiments in statics," Proceedings of the 2007 American Society for Engineering Education Annual Conference and Exposition.
15. O'Neill, R. Geiger, R.C., Csavina, K. and Orndoff, C., 2007, ""Making statics dynamic!" Combining Lecture and laboratory into an interdisciplinary, problem-based, active learning environment," Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition.
16. Williams II, R.L., He, X., Franklin, T. and Wang, S., 2007, Haptics-augmented engineering mechanics educational tools," World Transactions on Engineering and Technology Education, vol. 6(1), pp. 27-30.
17. Jong, I.C., 2005, "Teaching students work and virtual work method in statics: A guiding strategy with illustrative examples," Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition.
18. Newcomer, J.L., 2006 "Many problems, one solution method: Teaching Statics without special cases," 36th ASEE/IEEE Frontiers in Education Conference.
19. Gardner, A. and Jacobs, B., 2005, "Go and see and touch and feel – An introductory case study for Civil Engineering students", Proceedings of the 2005 ASEE/AAEE 4th Global Colloquium on Engineering Education, 26th – 30th September, Sydney, Australia.
20. http://ethics.tamu.edu/ethics/hyatt/hyatt2.htm, last visited on January 16, 2008.
21. Darmofal, D.L., Soderholm, D.H. and Brodeur, D.R., 2002, "Using concept maps and concept questions to enhance conceptual understanding," Proceedings of 32nd ASEE/IEEE Frontiers in Education Conference.