LEARNING MODULES FOR STATICS

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ABSTRACT

Classroom implementation of a new approach to teaching Statics is presented. The new approach, which was explained in the companion paper [1], is based on the need to address the important concepts of Statics first in isolation, and the recognition that students do not perceive the forces between rigid, inanimate objects. Hence, Statics instruction was revised to focus on individual concepts in the context of situations in which all the forces are readily perceived. In this paper we demonstrate an implementation of this approach that draws upon widely accepted classroom techniques to promote active learning: peer-to-peer collaboration, integration of assessment and feedback into classroom activities, and the use of concrete physical manipulatives. With the development of Learning Modules, which feature objects to manipulate or examine, PowerPoint Presentations and Concept Questions, the authors have transformed this instructional approach into practical classroom tools. The details of classroom implementation, extensive excerpts of the modules, and an assessment of the efficacy of this approach, are presented.

INTRODUCTION

In the companion paper [1] we elaborated upon the motivations for our substantial reinventing of Statics Instruction. In short, we are conscious of the distinct concepts which students need to confront in Statics, and we seek to expose students to one new concept at time. In addition, we recognize that students often have difficulty perceiving the forces between inanimate objects. Hence, we treat each of the core concepts of Statics within the context of forces which students can readily perceive: forces exerted by hand and forces that are made evident through the deformation or motion they induce. In this paper, we give extended examples of in-class instructional activities that dovetail with the progression of concepts and contexts described in the companion paper, and which are consistent with many approaches to improving learning that have been demonstrated in other subjects.

GENERAL APPROACHES TO IMPROVING LEARNING

In this section we describe several generally accepted techniques for improving learning outcomes that are relevant to our instructional approach. Students learn in part through a process of constantly comparing their understanding and predictions with observations of the world. Making comparisons with observations is one way of obtaining feedback, which is necessary to refining one’s understanding. Increasingly, it is appreciated that assessment, in this broad sense of testing one’s knowledge and understanding, must not be relegated to the end of the semester or even to several times during the semester; assessment must be fully integrated into learning [2].

Debating important questions with peers also has benefits. In these circumstances, students have to generate and articulate explanations of their reasons, and they have to argue their point of view;
generating explanations can increase learning [3,4]. Students must also listen to and comprehend the arguments of others. Finally, students have to weigh possibly opposing arguments and ultimately arrive at what they believe is the best answer. Collaboration between students, if harnessed appropriately and focused on salient issues, can be a powerful tool in learning [5].

Finally, for many subjects in the sciences or technologies, physical referents or manipulatives can serve to enhance learning. The use of manipulatives in a lecture environment accommodates students with a greater range of learning styles, as compared with only traditional lecture. As an example relevant to our implementation, students that learned about pulleys on real pulley systems were better able to solve real world problems compared to students who learned from line diagrams [6].

A classroom that integrates the above three elements of assessment, collaboration and manipulatives is one that actively engages students. Particularly in large classes, students learn more when they are actively engaged in learning [7-9].

INTEGRATING MANIPULATIVES, ASSESSMENT, AND COLLABORATION INTO THE STATICS CLASSROOM

We have integrated the elements just described to form a set of classroom activities, each designated as a Learning Module. Each Learning Module addresses a relatively small number of concepts from the concept sequence described in the companion paper, through a combination of desktop experiments or demonstrations, PowerPoint Presentations and Concept Questions. The purpose of each Learning Module is to acquaint students with the concept(s) in the context of a real artifact and to help students make firm connections between the symbolic representations of Statics and the physical features they represent.

If students are ultimately to apply Statics to objects, then, we believe, Statics must be learned, from the very beginning, in the context of real objects. The objects in our classrooms play two roles: they are the bodies whose equilibrium is considered, and often they are the bodies against which we exert forces and which exert forces on us. Objects may be physical artifacts which students can hold, the human body itself, or objects that are more conveniently depicted with, say, digital images. When the Learning Module involves an object, there is either a single copy of the object for the instructor to demonstrate in front of the class, or more often there are enough objects for every two or three students to share a copy. Many modules take advantage of particular object that has been specially designed to facilitate learning of a number of concepts (e.g., the couple, static equivalency, 2-D and 3-D equilibrium, pin joints). This object, shown in (fig.1-2), is referred to as the “L”.

![fig.1 “L” disconnected](image1.png)

![fig.2 “L” connected](image2.png)

Students are actively engaged in relating the object to the concepts by contemplating a series of conceptual questions that are interspersed in the PowerPoint presentation. Such questions help
students both to focus on the key ideas and to gauge their current level of their understanding. Students are invited to vote on each of the questions. This can be done through raising one of a set of colored note cards or through a modern electronic Classroom communication system. The performance on such questions offers the instructor real-time insights into the understanding of students, which can affect further instruction.

While in some instances, nearly all students will answer correctly, there is far more commonly a distribution of answers. In such cases, the instructor can suggest that students discuss the question with their neighbors. In addition, if appropriate, students are invited to seek to answer the question by manipulating the object they share. Much of the power of the technique proposed here resides in the combination of peer discussion and discovery learning associated manipulating the object in pursuit of conceptual understanding.

The instructor controls the pace of the Learning Module through the PowerPoint Presentation. Besides concept questions, typical presentations contain slides presenting basic information or theory, answers to questions, and depictions of how the situations contemplated are represented symbolically in Statics with free body diagrams and vectors.

**DESCRIPTIONS OF SELECTED LEARNING MODULES WITH EXAMPLES OF POWER POINT PRESENTATIONS**

In the following sections, we explain the progression of concepts in several key modules. In each case selected slides from the presentations are shown. In the electronic version of this paper, the full PowerPoint presentation is opened up if one clicks on the figure.

**Balancing simple objects with fingers and nutdrivers – equilibrium under actions of concentrated forces and couples**

The first five modules presented in this paper focus on balancing objects with fingers or smooth rods (which are modeled as applying normal concentrated forces) and nutdrivers (which are modeled as applying couples). As explained in detail in the companion paper [1], our goal is to make forces real by focusing on those forces that can be experienced through the senses of touch. Thus, we separate out and address the basic concepts of Statics, including forces, moments, couples, static equivalency, free body diagrams, and equilibrium in 2-D and 3-D, entirely without the need to invoke difficult-to-perceive forces between contacting inanimate objects. Only after this initial phase of Statics are students gradually introduced to contacts between inanimate objects, frictional forces and connections. This gradual transition from manually exerted forces to contacts between inanimate objects prepares students to better understand the loads acting at connections between bodies.

**Module I. entitled “Equilibrium of Forces”**, addresses the conditions that forces acting on a body must satisfy to maintain the body in equilibrium. In this module, students “discover” that balancing the downward force of the weight by an upward force is insufficient: one must also prevent the body from rotating. This is linked to the idea of a moment due to a force. Students confront this idea first in the context of a simple rectangular bar (Fig. 3), and then later consider a slightly more complex body, the “L”. Here is an example in which we take advantage of student intuition as to how to balance on object, and reconcile that intuition with the results of Statics. As a by-product, the idea of the centroid arises naturally (Fig. 4). Next, the possibility of using horizontal as well as vertical forces is introduced, along with the idea that there must be balance of forces in both horizontal and vertical directions (Fig. 5 and 6). It should be noted that the module has already touched
upon two common mistakes that students make: they simply neglect to include the requirement of moment balance and they allow for forces in some direction (say horizontal one) to be left unbalanced.

**Module I: Equilibrium of Forces**

**Consider supporting the member in the vertical plane using two smooth rods.**

<table>
<thead>
<tr>
<th>Is it possible to support it this way?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pl</td>
<td>Gr</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>Gr</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>Gr</td>
</tr>
<tr>
<td></td>
<td>Pl</td>
<td>Gr</td>
</tr>
</tbody>
</table>

**Consider supporting the member in the vertical plane using a rubber band.**

\[ \Sigma M|z = 0: xR – h^2W \]
\[ \Sigma F_y = 0: R = 3W \]
\[ x = \frac{2}{3} h \]

The band should be placed in line with the centroid of the L-shaped member in order to balance it.

**fig. 3 Module I - slide 1/13**  
**fig. 4 Module I - slide 7/13**

**Consider supporting the member in the vertical plane using two smooth rods.**

Can the body be supported by: one rod placed in region A and one rod placed in region B?  
Yes | Gr  
No  | Pl  

Can the body be supported by: one rod placed in region A and one rod placed in region C?  
Yes | Gr  
No  | Pl  

**fig. 5 Module I - slide 8/13**  
**fig. 6 Module I - slide 12/13**

**Module II**, entitled “*Couples in 2D*”, turns to the extremely important idea of the couple. We take the couple to be a collection of forces which produce a net moment, but no net force. This concept is most useful when the forces forming the couple are applied to points in such a way that it is difficult to discern the individual forces; thus only their net effect is of interest. We believe that failure to distinguish the concepts of force, moment due to force about a point, and couple is at the root of many students’ errors in Statics. The idea of a couple is approached by having students first recognize that there are motions which a single force cannot produce no matter where it is applied (Fig. 7 and 8). Then, once a pair of forces is seen to be adequate, it also is seen that many pairs are equally capable (Fig. 9). This makes the physical meaning of static equivalence concrete. With that preparation, students then find that a nutdriver (or equally a screwdriver or other such implement), is also capable of producing the turning effect (Fig.10). Students are open to the idea that the nutdriver is applying
“something” which creates a tendency to rotate, but no tendency to translate; namely, a couple. The convenience of this representation is thus more apparent.

Module II: Couples in 2-D

**Initial configuration:**
- bar on a horizontal plane
- equal sized bands
- straightened out
- just about to be stretched

**Approximately 45°**

**Unloaded Configuration:**
 bands of equal length are unstretched

**Pivot the bar about its center stretching the bands equal amounts as shown**

**What is the smallest number of forces which can be used to maintain this pivoted position?**

1. Yes
2. No

**Can you produce this motion with more than one combination of forces?**

Yes

**All pairs of forces exerted by fingers produce statically equivalent effect**

**ΣM₀ = Fd - Ra = 0**

**Ra = Fd**

**ΣM₀ = Fd - M = 0**

**M = Fd**

Module III, entitled “Static Equivalence”, focuses students on the concept of static equivalence and seeks to highlight the distinctions between forces, moment of forces, and couples. We attempt to do this by taking advantage of various views of static equivalence: different combinations of forces that produce the same motion, different combinations of forces that balance the same applied loading (Fig. 11), and different combinations of forces that produce the same deformation (Fig. 12). Notice that here as well as in many other modules, we show the physical situation along with the representations in terms of vectors.
**Module III:**  **Statically Equivalent Loads**

Statically equivalent loads balance a bar in a vertical plane.

In **Module IV**, entitled “**Equilibrium with Forces and Couples in 2D**”, students contemplate planar situations where combinations of forces and couples are required for equilibrium. Students develop means of calculating the forces and couples necessary for balancing objects. At the same time, students develop an intuitive, qualitative sense for directions of forces and couples that provide equilibrium, which can also serve as a check on calculations (Fig.13 and 14).

**Module IV:**  **Equilibrium with forces and Couples in 2D**

Consider supporting the member in the orientation shown by applying only a couple to the nut, and a force through a supporting smooth rod.

What is the direction of the couple?

- Clockwise
- Counterclockwise

What is the direction of the couple at C?

- Clockwise
- Counterclockwise

fig. 11 Module III - slide 6/9

fig. 12 Module III - slide 9/9

fig. 13 Module IV - slide 2/6

fig. 14 Module IV - slide 5/6
Module V, entitled “Equilibrium with Forces and Couples in 3D”, focuses on the conditions of equilibrium in three dimensions, as seen in the context of the “L”. The first notion is that balancing an object in such cases requires one to consider rotations (moments) about more than a single axis. Thus, moments due to forces in 3-D should already have been addressed or are addressed in real-time within this module. A second theme in the first part of the module is how many supporting forces are necessary to balance the object. With three forces clearly being sufficient (students have the “L” to test this out), the relative values of the three forces is addressed (Fig. 15). Students consider both arriving at an answer through a superposition argument (Fig. 16), and systematically exploring the summation of forces and moments. Students are then asked whether a single force is sufficient to support the body (Fig. 17); in answering why it is not, students are lead to the notion of center of gravity (Fig. 18). Students next consider bodies on which combinations of forces and couples act. Questions regarding which combinations of supporting forces and couple can produce equilibrium (Fig. 19 and 20) lead to considerable debate between students; typically the answer is only resolved with a combination of manipulating the “L” and peer discussion. Subsequent slides reinforce what students have learned earlier in 2-D regarding how a couple contributes to the moment summation, but not to the force summation. There is additional complexity of recognizing that the couple contributes to the moment summation about one axis only.

Module V: **Equilibrium in 3-D**

**Equilibrium in 3-D**

Consider supporting the member in the orientation shown with one finger under each of the points A, B and C. What are the force magnitudes at A, B and C in order from smallest to largest?

- AB is 5 cm long and weighs 5 N, BC is 7 cm long and weighs 7 N
- the mass is uniformly distributed.

<table>
<thead>
<tr>
<th>ABC</th>
<th>BCA</th>
<th>CAB</th>
<th>ACB</th>
<th>CBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr</td>
<td>Pt</td>
<td>Bt</td>
<td>Yc</td>
<td>Wh</td>
</tr>
</tbody>
</table>

fig. 15 Module V - slide 2/35

**Intuitive approach**

Combine:
- forces required to balance weight of AB alone
- forces required to balance weight of BC alone

ail.15 Module V - slide 4/35

**Equilibrium in 3-D: Center of Gravity**

Locate single force which is statically equivalent to the 7 N and 5 N forces

12 N force must produce the same moments $M_x$ and $M_y$ as the original forces:

$\Sigma M_{Bx} = -7(7/2) = -12 y_e \quad y_e = 49/24 \text{ cm}$

Center of gravity

“L” member cannot be supported by one finger under some point of the body, because the “L” center of gravity is located outside its boundary

fig. 17 Module V - slide 14/35

fig. 18 Module V - slide 15/35
Equilibrium involving distributed contact forces, with and without friction

In many practical situations, the interaction between objects occurs not over a small region, but over an extended surface. We approach this gradually, first treating situations in which the force is distributed uniformly over the area of contact and is, therefore, statically equivalent to a force acting at the midpoint of contact; later we consider nonuniformly distributed contact forces. In these modules students first focus on contacts between inanimate objects, although we continue to include, as appropriate, situations in which forces are perceived through the sense of touch or are evident by virtue of the deformations they cause.

Up to this point, contact forces, whether between hand and object or between inanimate objects, have acted exclusively in the normal direction; friction has been neglected. While friction forces are addressed at the end of a typical Statics course, it is our contention that connections between bodies (e.g., pin joints), which are based on the neglect of friction, cannot truly be understood without appreciating what friction forces can exert. Therefore, in our Statics courses we address friction before structures and machines, and we take full advantage of the ability of students to perceive, with the sense of touch, those forces which are exerted by hand.

Module VI, entitled "Equilibrium with Uniform Contact", first addresses problems with blocks resting on each other; although these involve inanimate contacts, they are sufficiently familiar to students to be accessible. As can be seen in Fig. 21, we can delve into issues that are often subject to confusion. In particular, normal forces are often, without thought, equated to weight, and the force between two contacting bodies is sometimes incorrectly included in the free body diagram in which both bodies are included. With this module, students come to see that a free body diagram can include a single part or several distinct parts.

An even richer set of problems can be considered by also including cords, another situation of inanimate objects exerting forces with which students are at least superficially familiar. Students are shown a realistic embodiment of the connection between cords and blocks, and acquainted with the detailed way in which the individual parts exert forces on one another (Fig. 22). Then, students are confronted with a variety of problems involving sets of parts, gaining experience with the ideas that the normal force between bodies is an unknown to be determined and that one can collect bodies in different ways to form free body diagrams (Fig. 23-24).

Module VI: Uniform Contact Forces
How many errors are there in this FBD of B and C as a unit?

(Blocks B and C are enlarged)


fig. 21 Module VI - slide 10/22

Module VII, entitled “Equilibrium with Nonuniform Contact”, addresses situations in which bodies exert on one another force distributions which are not uniform. Thus, the presumption in the previous module that the net force acts through the center of the contact between bodies is revisited, first in the context of forces exerted by hand (Fig. 25 and 26). After illustrating this non-uniformity with both equilibrium arguments and evidence of deformation (Fig. 27), students can contemplate situations in which the changing location of the net force is critical to the solution and can be determined from equilibrium (Fig. 28 and 29). Now, students can also appreciate the basis for the net force and couple that are present in fixed or cantilevered support (Fig. 30).

Module VII:  Equilibrium with Nonuniform Contact
Nonuniform Contact
Support member by resting it on your hand located at various positions

Does hand always exert a net force which acts through the center of the area of contact?

Yes

No

fig. 25 Module VII - slide 1/20

Deformation of the supporting foam seen as evidence that the distribution of contact force between the two bodies (puncher and foam block) is non-uniform

fig. 27 Module VII - slide 6/20

The member’s weight is supported by a cord attached to the right hook, and by a board under the left portion of the member.

Which of the following is true?

WB  There is only one tension \( T \) which will maintain equilibrium

PL  There is a lower limit and an upper limit to the tensions \( T \) that can maintain equilibrium

RL  There is a lower limit to the tensions \( T \) that can maintain equilibrium, but no upper limit

YL  There is an upper limit to the tensions \( T \) that can maintain equilibrium, but no lower limit

fig. 28 Module VII - slide 8/20

In both cases the combination of forces \( N_1, N_2 \) must be equivalent to:
- a force to balance weight
- a couple to balance the moment created by weight

\[
\begin{align*}
\chi &= c \\
T_{\text{min}}, F_{\text{max}} &
\end{align*}
\]

\[
\begin{align*}
0 < x < c \\
T_{\text{min}} < T < T_{\text{max}}
\end{align*}
\]

\[
\begin{align*}
\chi &= 0 \\
T_{\text{min}}, F_{\text{min}} &
\end{align*}
\]

fig. 29 Module VII - slide 10/20

fig. 30 Module VII - slide 16/20
In Module VIII, entitled “Contact with Friction” we introduce students to the effects of friction forces, first in the context of forces they can exert by hand. One important idea to convey (Fig. 31) is that the friction force between two bodies seeks to maintain equilibrium; the friction force is related to the normal force only if slip is impending or occurring (this is an idea that cannot be repeated too often in Statics). Next, we consider how friction forces applied at distant points can together create a moment that provides equilibrium (Fig. 32). When bodies contact one another over some area, then the collection of friction forces between them can create couples; the couple created depends on both the forces and on their distribution (Fig. 33-37). Finally, such arguments are applied to the loads that a gripping hand can apply to a cylindrical object. By contrasting the net forces and couples which require friction and those that are the results of only normal forces, the ground is prepared for the standard approximations of a pin joint (Fig. 38).

**Module VIII: Contact with Friction**

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**Fig. 31 Module VIII - slide 2/34**

Contact with friction

Body of known weight $W$ is maintained in equilibrium by two squeezing fingers as shown.

Which forces if any can be determined from equilibrium?

- Normal forces
- Friction forces
- Normal and friction forces
- No forces

---

**Fig. 32 Module VIII - slide 5/34**

Contact with friction

Which one is the correct FBD?

---

**Fig. 33 Module VIII - slide 13/34**

Try supporting the member in horizontal position with fingers on front and back sides in two different ways.

Why can you balance it with grip B, but not with grip A?

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**Fig. 34 Module VIII - slide 20/34**

Contact with friction

- contact areas A and B have the same vertical dimension
- contact area B has larger horizontal dimension than A

Vertical forces in grip B are farther apart – create larger couple for same normal force exerted by fingers.
EXPERIENCE IN THE CLASSROOM AND IMPACT ON LEARNING

The materials just described have been implemented in our classrooms for the past two years. One module per week is used in class, on average, with modules taking from 10 minutes up to, in rarer cases, nearly an entire lecture period. In the case of Steif’s class, homework assignments have also been revamped to reflect the initial focus on situations in which forces are readily perceived by students. Thus, there are a number of problems involving balancing objects similar to those considered in class. Only after week 6 of the class (in a 14-week semester) do students start solving “traditional” Statics problems that might involve mechanical hardware and structures, with supports and connections.

It has been our sense that these materials have markedly changed our classes for the better. We have also sought to develop ways of quantifying the impact of our new approach. This is not a trivial task. This has been a complete revamping of the topic sequence, as well as the activities in class. The significant improvement we perceive is not one that could be attributed to a single learning episode; rather it is due to cumulative effects of confronting concepts one at a time, in the context of objects to
which those concepts are relevant, and with students given constant opportunities to test their understanding and refine that understanding through interaction with peers and the instructor. Indeed, one could argue that the approach must produce improved learning outcomes, since it utilizes several techniques that are known to be effective in their own right.

Perhaps the only fair means of quantitative assessment might be to have one of the authors teach two sections of Statics simultaneously, one with the new approach and one with the traditional approach. While one of the authors had an opportunity to do this, after having experienced the markedly heightened level of student engagement, that author could not in good conscious teach half of the students in a manner that intuition suggested strongly was inferior.

One means of quantifying the improvement in conceptual understanding which the new approach produces is based on a Statics Concept Inventory, recently developed by one of the authors [10]. This is a multiple-choice test with questions testing key concepts in Statics, including the forces in free body diagrams, static equivalence, forces at connections and at frictional contacts, and conditions of equilibrium. In fact, one motivation for developing this test was to have a tool for quantifying the effectiveness of various instructional interventions. Recent psychometric analysis of the current version of this test has shown it to be reliable and internally valid. This test was administered to students in the Department of Mechanical Engineering at CMU, both at the beginning and just after completion of the Statics course. The mean and standard deviation for the pre-test was 10.6 and 4.1, and the mean and standard deviation for the post-test was 20.3 and 3.5; the maximum score is 27. Based on the 105 students who took both the pre- and post-tests, the probability that the difference between the pre- and post-tests is due to random variation is p < 0.001.

For a sense of the significance of the increase in conceptual understanding as indicated by scores on the inventory, we consider work done on the widely recognized Force Concept Inventory (FCI) which tests conceptual understanding in freshman level Newtonian mechanics. Hake [11] suggested using “normalized gain” to gauge the improvement on the Force Concept Inventory. “Normalized gain” is defined as the actual improvement in the class average scores from pre- to post-test normalized by the maximum possible improvement:

\[
\text{Normalized Gain} = \frac{(\text{Post-test}) - (\text{Pre-Test})}{(\text{Maximum Possible}) - (\text{Pre-test})}
\]

Hake analyzed the results from over 6000 students taking the FCI. He found that introductory physics courses taught with a "traditional" teaching style had normalized gains of 0.23±0.04, in spite of the wide range of student initial abilities. By contrast, the normalized gains associated with courses Hake designates as "interactive engagement" courses are in the range 0.48 ± 0.14, a statistically significant difference. After examining and discarding a number of possible explanations for these results, Hake concluded that the teaching methods employed in the courses accounted for the difference.

For the students in the CMU class of Fall 2003, who participated in the instructional sequence and class activities described in this paper and its companion, the normalized gain on the Statics Concept Inventory was 0.59, solidly in the range which Hake designates as "interactive engagement". Of course, to solidify this argument it would be helpful to have a study which indicates that this level of normalized gain on the Statics Concept Inventory is indeed a sign of considerable conceptual advancement.

To gauge the reactions of students to our new approach, we surveyed students, sometimes regarding the overall approach, and sometimes regarding individual modules. Results of surveys that were conducted in the Fall 2003 are given in Tables 1 and 2. As can be seen, student reaction to this instructional approach has been very positive.

**Table 1. Results of student survey at Miami University. Responses 0 to 4 correspond to strongly disagree (0) and strongly agree (4).**
The focus on forces and couples that you can exert (e.g. manipulating objects with fingers and nut drivers; maintaining your own equilibrium) help your understanding of the concepts of Statics.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>The focus on forces and couples that you can exert (e.g. manipulating objects with fingers and nut drivers; maintaining your own equilibrium) help your understanding of the concepts of Statics.</td>
<td>31</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3.65</td>
</tr>
<tr>
<td>Power Point presentations help your understanding of the concepts of Statics.</td>
<td>28</td>
<td>17</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3.59</td>
</tr>
<tr>
<td>Asking of concept questions (questions you voted on with colored cards) in lecture helped your understanding.</td>
<td>27</td>
<td>16</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3.52</td>
</tr>
<tr>
<td>Demonstrations (e.g., friction, moment of inertia) have been helpful.</td>
<td>32</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3.65</td>
</tr>
</tbody>
</table>

Table 2. Results of student survey at Carnegie Mellon University. Students were asked how much each of the classroom elements contributed to their learning in Statics. Responses correspond to: nothing (0); very little (1); modest amount (2); quite a bit (3); a lot (4).

<table>
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<th></th>
<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voting on questions with colored cards</td>
<td>18</td>
<td>28</td>
<td>33</td>
<td>15</td>
<td>4</td>
<td>2.42</td>
</tr>
<tr>
<td>PowerPoint Presentations (aside from voting)</td>
<td>13</td>
<td>29</td>
<td>37</td>
<td>16</td>
<td>3</td>
<td>2.34</td>
</tr>
<tr>
<td>Manipulating objects in class.</td>
<td>26</td>
<td>26</td>
<td>35</td>
<td>9</td>
<td>2</td>
<td>2.67</td>
</tr>
</tbody>
</table>

SUMMARY AND CONCLUSIONS

In this paper we have shown how a new instructional approach to Statics is implemented. This approach, which was described at greater length in the companion paper [1], combines two core ideas. First, that there are distinct concepts which students need to learn in Statics, and that students should confront each of these concepts initially in isolation. Second, as appreciated from the literature on physics education, students often have difficulty perceiving the forces between inanimate objects. Hence, we seek to isolate each of the core concepts of Statics, and to address them within the context of forces which students can readily perceive: forces exerted by hand and forces that are made evident through the deformation or motion they induce. The implementation of these core ideas takes advantage of several widely accepted classroom techniques that promote active learning: peer-to-peer collaboration, integration of assessment and feedback into classroom activities, and the use of concrete physical manipulatives. Implementation is carried out through “Learning Modules”, which include objects to manipulate or examine, PowerPoint Presentations and Concept Questions. The notion of Learning Modules is applicable to a wide range of engineering and scientific subjects.

Excerpts from the Learning Modules corresponding to a significant portion of our sequence of topics in Statics are presented in this paper, along with explanations of the ideas developed in each portion of the modules. Since the instructional approach presented here is focused on improving students overall understanding of concepts in Statics, we have sought to judge the effectiveness of the approach by measuring student gains on a recently developed Statics Concept Inventory [10]. We have found that the normalized gain – the actual improvement relative maximum possible improvement – was quite high, in the range that Hake [11], who studied results of the Force Concept Inventory, associated with active engagement courses. Between that quantification, and the very positive response of students in surveys, we have concluded that our approach has merit and that its further development and assessment are worthwhile.
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BIBLIOGRAPHIC INFORMATION