AC 2012-4151: GUIDED DISCOVERY MODULES FOR STATICS

Dr. Javier Angel Kypuros, University of Texas, Pan American

Javier Kypuros received a B.S.E. in mechanical engineering from Princeton University in 1996. He later received a M.S.E. and Ph.D. in mechanical engineering in 1998 and 2001 from the University of Texas, Austin. Kypuros began his career at the University of Texas, El Paso in 2001 and later joined the faculty at the University of Texas, Pan American (UTPA) in 2002. He is currently an Associate Professor and departmental ABET Coordinator. Kypuros received the UTPA Faculty Excellence Award for Teaching from the College of Engineering and Computer Science in 2012. His research interests include dynamic systems and controls, bond graphs, and vehicle systems.

Prof. Martin William Knecht, South Texas College
Prof. Constantine Tarawneh, University of Texas, Pan American

Constantine Tarawneh obtained a B.S. degree in mechanical engineering from the University of Jordan, Amman in 1996 with a specialization in the thermal sciences area, and obtained M.S. and Ph.D. degrees in mechanical engineering from the University of Nebraska, Lincoln (UNL) in 1999 and 2003, respectively. Tarawneh joined the University of Texas, Pan American (UTPA) in 2003 and currently holds the rank of Associate Professor of mechanical engineering. Tarawneh received the UT System Board of Regents' Outstanding Faculty Award in 2009 and six other departmental faculty outstanding teaching awards. Tarawneh serves the department as Graduate Program Director. Current expertise includes experimental heat transfer, thermal sciences, acoustics and vibrations, and railroad bearing research.

Dr. Horacio Vasquez, University of Texas, Pan American
Robert D. Wrinkle, Center for Survey Research

Guided Discovery Modules for Statics

Abstract

Students notoriously struggle to master the concept of free body diagrams. In Statics, for example, they often fail to identify reaction forces, include nonexistent forces, and sketch diagrams that are not in static equilibrium. Confusion arises in distinguishing internal from external loads and their impact on free body diagrams. The problem is further exacerbated when student encounter moments in static equilibrium. They do not seem to understand how the components of a force generate moments about a primary axis and how those moments can be summed to determine the overall three-dimensional moment.

This paper presents a *Guided Discovery* module designed to reinforce proper conception of free body diagrams by physically illustrating the consequences of not accounting for all the correct loads. Furthermore, we also present a second module for moments of a force about a point or line. This module helps students physically visualize the process to better understand the directionality and magnitude of the force components and the moments generated.

Guided Discovery is a novel methodology that borrows aspects of *challenge-based instruction* and *discovery learning*. The method is designed to facilitate students' paths to discovery of key concepts that are often misinterpreted or not readily mastered. The method is optimized for short, in-class activities. It is a low-cost, active-learning method intended to bring laboratory-like experiences into the classroom to improve concept mastery and elucidate common misconceptions. The intent is to target concepts that students commonly fail to master and that negatively impact learning outcomes in later courses. The authors provide a brief overview of the methodology with illustrative examples.

The focus of this paper, however, is the description of two new modules that have been recently piloted in Statics courses at The University of Texas-Pan American (UTPA) and South Texas College (STC). The first is a moment module designed to help students properly determine three-dimensional moments. The second is a module used to help students formulate appropriately conceived free body diagrams. This paper describes both modules and provides preliminary observations resulting from the initial implementations.

Introduction

Part of the challenge of encouraging students to think critically about Engineering Mechanics is that some view the material as "disconnected facts and formulas" as opposed to "an interconnected web of concepts"[1]. There is a tendency to approach Mechanics problems by identifying the applicable equations as opposed to recognizing underlying concepts. It is not always students' tendency to critically evaluate the information given and methodically analyze it using their engineering intuition. Even when they do, often times they have preconceived misconceptions that hinder effective analysis. Effort must be made to refocus students so they approach Mechanics as "an interconnected web of concepts." Traditional pedagogical approaches alone do not encourage this. As such, alternative approaches must be devised.

Elby et al.[1,2,3] researched the role of students' perceptions of Physics in hindering concept mastery. The North Carolina State University Physics Education Research and Development Group, the largest physics education research group in the Nation, developed and researched the use of animation to assess physics concepts mastery[4,5]. Gray et al.[6,7] devised a format for Dynamics curriculum deemed "Interactive Dynamics." The format involved collaborative learning, computer simulations, and experimentation. Magill of Purdue University designed a series of inexpensive bench-top exercises used to demonstrate basic Mechanics principles[8,9]. Steif and Dollár developed a series of simple experiments and web applets used to demonstrate Statics concepts[10,11,12,13]. Everett et al.[14,15] developed counter intuitive Dynamics examples designed to expose students' misconceptions.

Education experts continue to urge Engineering educators to transform from a lecture-based paradigm to one that is more inquiry-based. The 2000 National Research Council report[16] indicated that "[s]ixth graders in a suburban school who were given inquiry-based physics instruction were shown to do better on conceptual physics problems than eleventh and twelfth grade physics students taught by conventional methods in the same school system." In spite of the potential advantages for student learning, there is a limited amount of research on the use of inquiry-based learning in Statics and Dynamics.

Despite advancements, widespread reform has not taken place because of (1) a reluctance to implement pedagogical changes and (2) deeply rooted student misconceptions. The authors contend that through the use of well-devised Guided Discovery modules, students become more engaged and are more prone to correctly interpret Engineering Mechanics concepts. Such modules can better engender properly conceived engineering intuition and better help contextualize concepts. These modules place emphasis on understanding the problem and not on simply trying to find the right answer(s). Moreover, they require the student to be actively involved in the process of discovering the answer.

Methods and Procedures

The methods and procedures described herein are discussed in more detail in [17] and results for several sample modules can be found in [18,19]. The modules are designed to use in place of select homework or lecture content and not simply be an addition to existing curriculum. The intent is to complement but not fully supplant existing curriculum. The modules share some common characteristics:

- *Inquiry-Based*. Modules, when possible, are purposely posed with "open-ended" questions that force students to demonstrate concept mastery by expressing through tasks, words, and presentation a deeper understanding of the concepts and material.
- *Cooperative-Learning*. The modules incorporate steps that require students to share knowledge, discuss answers, and arrive at conclusions through interaction.
- *Interactive*. The modules require students to interact physically or virtually with the physical system to solve problems.
- *Common Misconceptions*. The modules target common Statics and Dynamics misconceptions or fundamentals that students struggle to master early on.
- *Discovery*. The modules are designed to guide students to discover underlying principles and build properly formulated engineering intuition.

In addition to having common characteristics, these modules are implemented using a similar processes developed by Kypuros et al.[17] The *overall process* involves lecture, a pre-module assessment, a primary exercise, an intermediate assessment, a secondary exercise, and a post-module assessment. Each module includes the assessment questions (pre and post), handouts, supporting materials (such as videos, worksheets, reading material, etc.), list of equipment, and procedure.

Prior Modules

The modules in this section are described only briefly. For each, a reference is provided that describes the module in more detail including preliminary results.

A Gravity Module

Students tend to struggle with the idea that the size of an object is not what dictates its vertical acceleration. It seems counter-intuitive that, baring the influence of air drag, a feather will fall at the same rate as a bowling ball. It may be inconceivable that acceleration due to gravity is mass independent because students tend to associate acceleration directly with force and do not always distinguish the subtle yet important distinctions between force and acceleration. Moreover, it is not entirely intuitive that when looking at 2D particle motion in a gravity field the horizontal displacement is decoupled (independent) from the vertical displacement.

This module is intended to demystify some of these misconceptions and elucidate the nuisances that do cause vertical acceleration to change. In this module, students experiment with a variety of spheres like those depicted in Figure 1. They are presented a challenge. For example, they are presented two spheres and asked which will hit the ground first if released simultaneously from the same height. The variety of spheres is chosen to illustrate the concept and its exceptions. This module, its assessments, process, and preliminary results are detailed in [18].

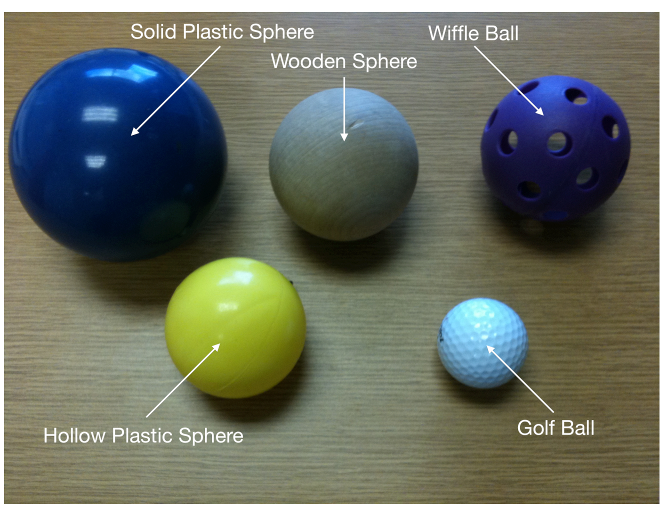
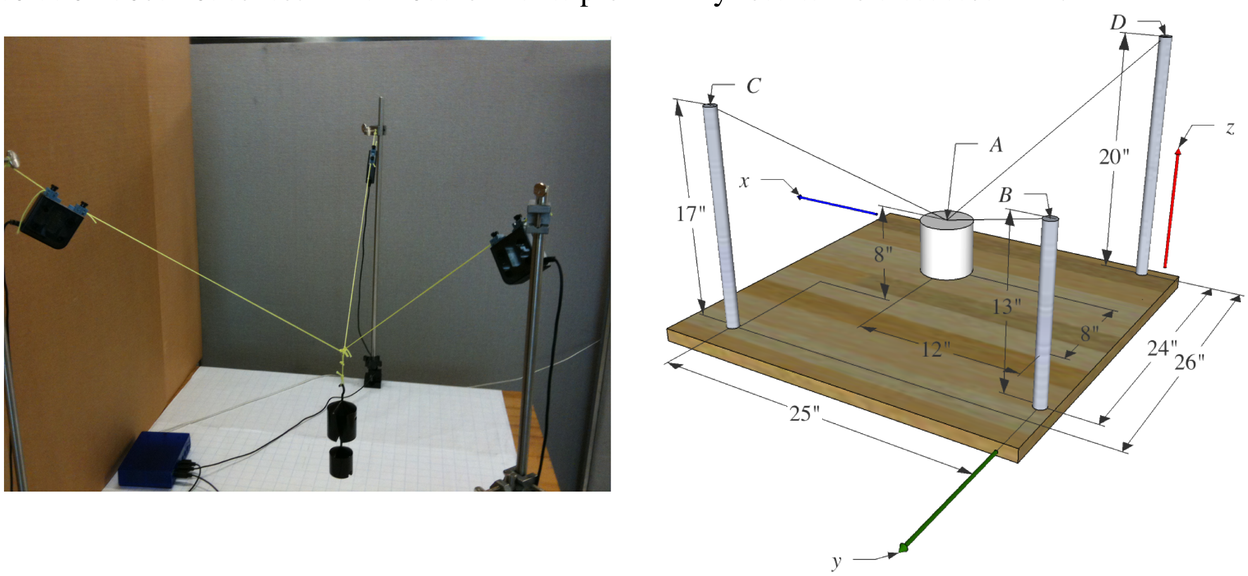


Figure 1: Spheres of different size, material, and density

A Vector Module

This module is designed to help students visualize vectors using a configurable system of cords to suspend a mass in a three-dimensional space. To that end, several bench-top configurations have been devised to elucidate vector mechanics concepts. As illustrated in the photo in Figure 2(a), an experimental apparatus is used to validate results and reinforce concept mastery. The forces in the cables are measured with load cells and are compared to the theoretically calculated values. This activity is designed to strengthen students' knowledge through practical application of concepts studied during the first quarter of Statics, such as position, unit vectors, free body diagrams, and equilibrium of particles.

The schematic in Figure 2(b) depicts a 3D rendering of the sample problem with dimensions. The students are tasked with determining a unit vector along the line of action of one of the cords. The potential solutions are chosen such that the answer can be surmised based on some basic concepts: (1) unit vectors are of a unit length (i.e. $\sqrt{u_x^2 + u_y^2 + u_z^2} = 1$), (2) the positive orientation of axes changes the sign of vector components, and (3) cords apply force in tension (not compression). Students fail to distinguish between the length of the vector and its projections along the primary axes. Moreover, they can be readily confused if the axes are not oriented with directionality similar to problems they are accustomed to in the textbook (i.e. a right-handed Cartesian coordinate system). When mistakenly arriving at a solution that implies that the vector force along a cord is in compression, students sometimes fail to recognize that the solution does not sense. This module and its preliminary results are discussed in [18].



(a) (b)

Figure 2: (a) Experimental apparatus and (b) 3D rendering

A Pulley Module

First presented in [19], the pulley module was developed to help students understand the use of pulleys to generate a mechanical advantage. Students often fail to understand that the motions of the pulleys (i.e. displacements and velocities) are interrelated through simple constraints. Furthermore, they do not always recognize that the same constraints are used to relate the forces and determine the mechanical advantage. The concepts and/or misconceptions this module is designed to address are (1) masses attached through pulley systems have interdependent motion that can be represented through simple mathematical constraints and (2) the equations used to quantify the mechanical advantage relate not only the tensions or forces but the displacements and velocities also.

Whenever possible the problem is presented as a real-world-inspired challenge. The challenge used for the pulley module is

> "You stalled your prize 6500 lb, heavy-duty, 4x4 in a creek bed at the bottom of an embankment about 15 ft away – 9 ft down and 12 ft over (refer to Figure 3). The engine will not turn over because the ignition circuit was damaged when it got wet. Unfortunately the only winch available is attached to your friend's ATV. It is only rated at a maximum 1750 lbs and operates with a constant line speed of 15 feet per minute (FPM). However, it has plenty of cable (200 ft), and you have access to a winch kit with one heavy-duty pulley block (rated at 10,000 lbs), two light duty pulley blocks (rated at 2500 lbs), two 10-ft tow straps (rated at 20,000 lbs), and two shackles (rated at 3000 lbs). (Items are depicted in Figure 3) Shackles and two straps may be used to attach cable, pulleys, or tow straps to the bumper of the truck. There are numerous trees that could be used to anchor the ATV and to attach tow straps with pulley blocks. From the choices provided, choose an option that will pull your truck up the embankment without exceeding the rating of any of the components used. Determine the tension in the cable and the time that will be needed to move the truck up the embankment. Also, explain any assumptions you made."

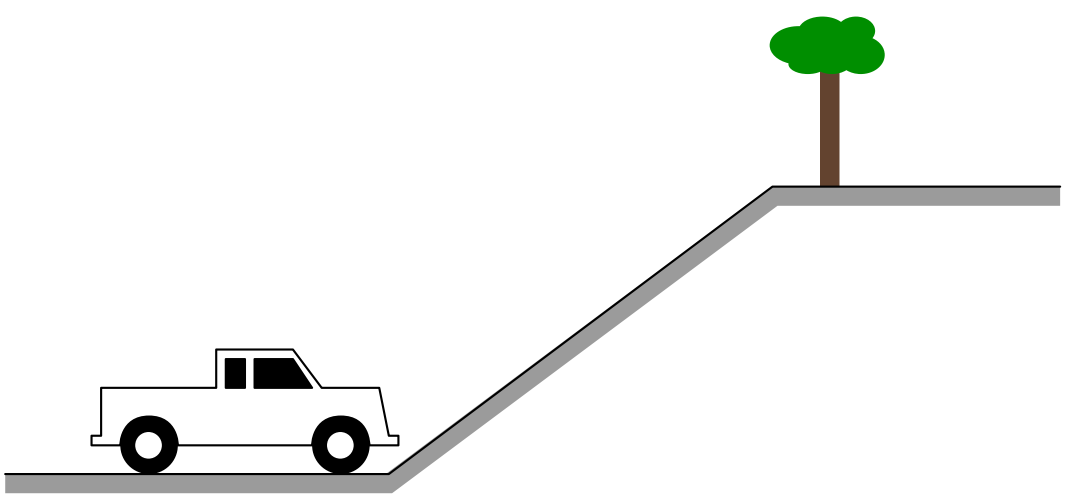


Figure 3: Truck at bottom of embankment

New Modules

A Moment Module

Students have difficulty in determining the moment of a force about a point or about a line. Some common errors students make occur while expressing positions and forces in Cartesian form. They also struggle to properly use matrix and vector algebra to compute moments, forces, etc. Students are in need of a more practical understanding of the moment of a force in order to assess whether or not the obtained results of the moment's magnitude, direction, and units are appropriate.

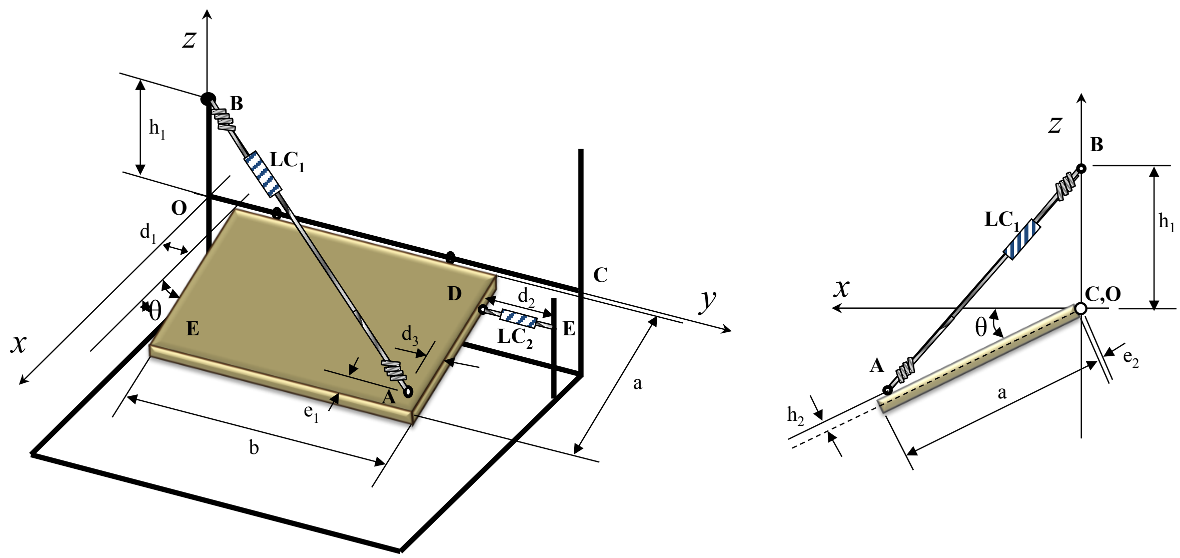


Figure 4: Experimental setup of the moment module

The goal of this module is to enhance understanding and visualization of vector moments. The module consists of a setup illustrated in Figure 4 that is assembled and instrumented by the students. The forces acting in the two ropes are measured using load cells or spring scales and compared to the theoretically determined forces from equilibrium analysis. As shown in Figure 4, one side of the wooden platform is connected with eyebolts around a frictionless rod *OC* that allows the platform to freely rotate about the *y*-axis. Two ropes with load cells LC_1 and LC_2 are connected to the platform to keep it in static equilibrium at an angle θ. The rope *DE* is aligned parallel to the *y*-axis for simplicity. Students specify and use a fixed coordinate system to measure all key dimensions necessary to draw the free body diagram of the wooden platform. They are tasked with determining the forces measured by the load cells or the weight of the platform.

A Free Body Diagram Module

The objectives of this activity are to develop a student's skills in (1) creating and using free body diagrams (FBDs), (2) applying equilibrium conditions to a multi-body system, and (3) determining if a system is in equilibrium. The FBDs focus on contact forces between multiple objects, a force typically modeled improperly by freshman/sophomore students. One of the most common errors is assuming the normal force between two objects is always equal to one of the objects' weights. Students need to test if a system is in equilibrium. Classical statics problems typically assume a system is already in equilibrium and ask for the unknown forces that will satisfy the equilibrium conditions.

The students are presented with a system that consists of an open bottomed cylinder with a pair of identical spheres (golf balls) nested inside. Friction between objects is assumed to be negligible. The students are given several of these systems with varying cylinder mass and radii. The students determine if the system is in static equilibrium or not. The activity begins with the instructor demonstrating the equilibrium of a closed bottom cylinder with a pair of nested spheres and then an open bottom cylinder. It is observed that the closed bottom system will always be in equilibrium regardless of relative mass and radii of the balls and cylinder while the open bottom will not always be in equilibrium. As a challenge, the students must determine whether a particular open bottomed system is in equilibrium (see Figure 5). In the first system, the cylinder has a mass one half that of the spheres and a radius about 60% larger than the spheres. One is stable and the other unstable.

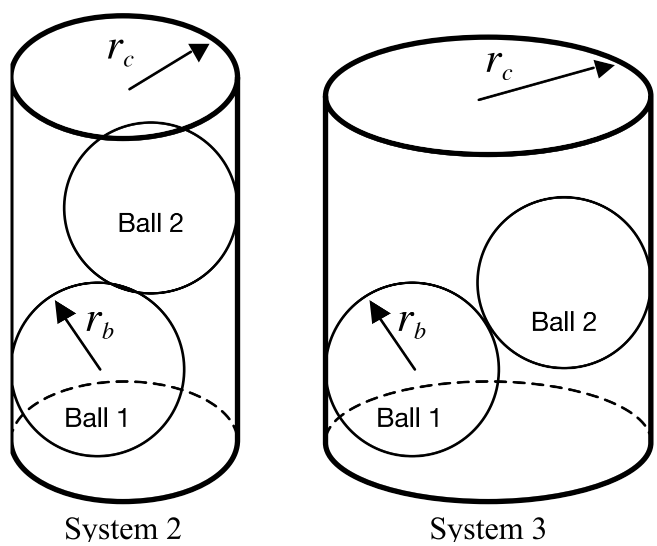


Figure 5: Cylinder-sphere combinations

Results

As with any pedagogical experiment, first attempts are rarely glowing successes; they are a learning process for the instructor. Nonetheless, recently implemented new modules have resulted in a number of observations that may lead to improvements necessary to insure persistent positive impact on student concept mastery and engagement. Some of those observations are summarized below.

The moment module was first implemented in the Fall 2011 semester. The results that were obtained are presented in Table 1. The average grade in the pre-test was 59.4% and in the post-test was 67.9%, which indicates an improvement of 8.5%. However, in the final exam a follow-up question related to the module was included and students got an average grade of 53.9.

Table 1: Data related to the moment module for Fall 2011

Students in Statics	37
Students that completed the pre-test and post-test	28 (75.7%)
Average grade of moments module pre-test	59.4%
Average grade of moments module post-test	67.9%
Average grade of moments module question in final exam	53.9%

The following recommendations by the instructor should be taken into account to obtain better results when performing this module:

- All students need to study a handout with information about the module before they perform the hands-on activity. A video might be created with similar information to the one presented in the handout.
- If possible, the hands-on activity should be performed with more than the 50-minute period dedicated to it, or some of the bench-top setup should be preconfigured to expedite the process.
- All students need to complete the homework after the hands-on activity as a team activity, and all the members of a team should get the same results. It is recommended to announce to the class that a randomly chosen team would present the results to the class in order to create higher expectations and better preparation by the students to go public.

As these modules are again implemented during the next semesters, the instructors expect to improve them and to obtain better results by getting students more engaged before, during, and after the hands-on activities. It is important that these modules count towards the grade of the course so that students get an additional incentive to do the work that is required. Definitely, students need to show up better prepared to the hands-on activity so that it can be completed in an efficient and timely manner. Student teams might be formed a week before the hands-on activity and an assignment might be given so that they start getting prepared as a team to complete the experiment.

With regards to the Free Body Diagram module, there was no marked improvement between pre- and post-tests. However, the following instructor observations point to changes that could significantly impact the efficacy of this module:

1. "The activity was originally done over a single class period with the exception of the follow-up assignment and post test. As a result, the activity felt a bit rushed at the end of the class period. It may be helpful for the students to work out the last two systems (with the change in radii) outside of class bring their conclusions to the next class period."

2. “Students seemed to struggle with the geometry of the problem. This may have taken the focus away from the main objectives of FBDs and equilibrium. Originally I had worked out the geometry of the problem algebraically substituting in dimensions in towards the end of the problem. In the future I will work out all necessary angles and dimensions up front.”
3. “I scored the activity as an extra credit assignment. The students may have perceived this to mean that activity had no pedagogical value in the class or just didn’t apply themselves as they would on normal assignments. In the future the activity will be better incorporated into the class with a grade attached.”

Conclusions and Future Work

Each of the modules described herein have been implemented at least once. Some shortcomings have been identified and need to be addressed in subsequent iterations. Furthermore, the module procedure was not strictly adhered to in initial implementations. This issue in particular must be revisited to determine if the process and be streamlined or optimized. The modules in their current form require more than one lecture. To expedite the process, pre-module material in the form of handouts, videos, and the like have been used. However, students do not uniformly complete these activities before coming to class. These inconsistencies have undoubtedly had a negative impact on assessment results. In future iterations, measures must be implemented to insure consistent participation throughout the process. It is the opinion of the investigators that consistent student involvement is the key.

In future implementations, we will adapt strategies to improve persistent participation and separate out the assessment results of those who do not complete pre-module activities. Moreover, modules procedures will be minimized to include only critical steps deemed necessary to improve understanding. For example, the vector and moment modules mentioned above require significant time to set up. Instead of requiring students to set up the bench-top experiment, it can be preconfigured. This would save considerable time and facilitate completing these modules within one rather than two class periods. This is important because, in collecting data, a significant number of participants did not participate over the entire process. They may have missed a lecture, for instance. For Guided Discovery strategies to be effective, students must be actively involved and present throughout.

Acknowledgements

The authors gratefully acknowledge the support of Division of Undergraduate Education of the National Science Foundation. This research is supported by the Course Curriculum and Laboratory Improvement Program through grant number DUE-0837779.

References

[1] Elby, A., “Helping physics students learn how to learn,” American Journal of Physics, 69, No. 7, 2001, pp. S54–S64.
[2] Lising, L. and Elby, A., “The impact of epistemology on learning: A case study from introductory physics,” *American Journal of Physics*, 73, No. 4, 2005, pp. 372–382.
[3] Hammer, D. and Elby, A., “Tapping epistemological resources for learning physics,” *Journal of Learning Sciences*, 12, 2003, pp. 53–90.
[4] Beichner, R., “Instructional technology research and development in a us physics education group,” *European Journal of Engineering Education*, 31, No. 4, 2006.
[5] Dancy, M. H. and Beichner, R., “Impact of animation on assessment of conceptual understanding in physics,” *Physics Review Special Topics - Physics Education Research*, 2, 2006.
[6] Yaeger, P. M., Marra,R., M., Gray, G. L. and Costanzo. F., “Assessing new ways of teaching dynamics: An ongoing program to improve teaching, learning, and assessment,” *Proceedings of the ASEE Annual Conference*, 1999.
[7] Gray, G. L. and Costanzo, F., “Interactive dynamics: A collaborative approach to learning undergraduate dynamics,” *Proceedings of the ASEE Annual Conference*, 1999.
[8] Magill, M. A., “Classroom models for illustrating dynamics principles part i. – particle kinematics and kinetics,” *Proceedings of the ASEE Annual Conference*, 1997.
[9] Magill, M. A., “Classroom models for illustrating dynamics principles part ii. – rigid body kinematics and kinetics,” *Proceedings of the ASEE Annual Conference*, 1997.
[10] Steif, P. S. and Dollár, A., “Enriching statics instruction with physical objects,” *Proceedings of the ASEE Annual Conference*, 2002.
[11] Dollár, A. and Steif, P. S, “Understanding internal loading through hands-on experiences,” *Proceedings of the ASEE Annual Conference*, 2002.
[12] Steif, P. S. and Dollár, A., “A new approach to teaching and learning statics,” *Proceedings of the ASEE Annual Conference*, 2003.
[13] Dollár, A. and Steif, P. S., “Learning modules for the statics classroom,” *Proceedings of the ASEE Annual Conference*, 2003.
[14] Everett, L. J. and Villa, E. Q., “Assessment results of multi-intelligence methods used in dynamics,” *Proceedings of the ASEE Annual Conference*, 2006.
[15] Everett, L. J. and Villa, E. Q., “Increasing success in dynamics course through multi-intelligence methods and peer facilitation,” *Proceedings of the ASEE Annual Conference*, 2005.
[16] Bransford, J. D., Brown, A. L., and Cocking, R., editors. *How People Learn: Brain, Mind, Experience, and School* (Expanded Edition). National Academies Press, 2000.
[17] Kypuros, J. A. and Tarawneh, C., “Multimodal Modules for Non-Calculus-Based Engineering Mechanics Curriculum,” *Proceedings of the Frontiers in Education Conference*, 2008.
[18] Kypuros, J. A., Tarawneh, C., Vasquez, H., Knecht, M., and Wrinkle, R., “Guided Discovery Modules for Engineering Mechanics,” *Journal of Applications and Practices in Engineering Education*, 2, No. 1, 2011.
[19] Kypuros, J.A., Vasquez, H., Tarawneh, C., Knecht, M., and Wrinkle, R., 2011, “Guided Discovery Modules for Statics and Dynamics,” *Proceedings of the ASEE Conference and Exposition*.