Work In Progress: Hands On Wednesday (HOW) - An Introduction to Statics Experience

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Hands-On Wednesday (HOW) – An Experiential Introduction to Statics Experience

Abstract

The impacts of active learning have been well-documented in STEM education literature; however, few studies attempt to decouple hands-on learning from the catch-all term. In this study, a series of hands-on activities is developed and deployed throughout an Introduction to Statics (Statics) course in an attempt to improve student understanding and confidence in core concepts. In the hands-on class sessions, students interact and experiment with physical representations of previously completed homework problems or brand-new Statics-related scenarios. These experimental setups provide an environment where students can get immediate, physical, feedback based on quantities such as loads applied, distances selected, and or balance points. Data from this 90-student enrolled course were collected using the SALG assessment tool. Hierarchical multiple regression models were constructed to isolate the effects of Hands-On Wednesday after controlling for student background and the effects of attending lecture. While this single study of a single course showed several positive effects of adding hands-on activities to a core engineering course, future studies should be done to observe longitudinal effects as well as outcomes for underrepresented minority groups.

Introduction

The rapidly evolving landscape of the workforce and the growing emphasis on the necessity of transferrable skills has been driving a shift toward more active learning practices in higher education [1]. Active learning methodologies can provide students with opportunities to develop the skills needed by graduates in the 21st century. These skills include learning and innovation skills such as critical thinking, problem solving, and life and career skills such as collaboration [2]. Through engagement in firsthand learning experiences, students begin to figure things out for themselves, develop confidence in their analytical abilities, learn to connect with the world around them, and discover how to use their innate curiosity to uncover the power of their own learning abilities [3].

The early core engineering science courses set the foundational knowledge on which future content is directly based for the majority of engineering students. Students need to develop a thorough understanding of core concepts upon which they will build in subsequent courses. Without this foundational knowledge and skill set, as well as confidence in their expertise to apply it to new contexts, students are less likely to persist in pursuing engineering as a future profession [4] – [5].

This study describes a specific set of learning activities using hands-on active learning to engage students in a gateway engineering course, Introduction to Statics. The instructor redesigned the course from traditional, lecture-based delivery after becoming frustrated with students' limited understanding of core concepts and skills in subsequent courses. Hands-On Wednesdays (HOW) introduced weekly hands-on activities for students to practice applying the concepts discussed in lectures and practiced in problem sets that were completed as homework. After situating this work within the broader empirical literature on active learning, HOW is described.

Current Research in the Field

Active learning is often defined by describing what it is not. These definitions frame active learning as the opposite of the traditional educational experiences in which an expert provides knowledge through lecture while students passively receive the information. As Prince [6] describes it, active learning is any style of instructional methodology in which students are engaged in the learning process. This requires the use of relevant and authentic learning activities through which students explore and develop their knowledge and skills, both those relating directly to the content as well as transferrable success skills. For the context of the study discussed within this paper, active learning is referred to as the hands-on activities learners engage with in class that require problem solving, critical thinking, and collaboration with peers.

Chi and Wylie [7] introduced the Interactive, Constructive, Active, Passive (ICAP) framework, which describes engagement through types of overt behaviors that students can undertake in order to elicit different learning processes of varying effectiveness. In the ICAP hypothesis, activities that include interactive behaviors yield the best learning results, followed by constructive behaviors, active behaviors, and passive behaviors, respectively [7] – [8]. Interactive, constructive, and active experiences, as defined within the ICAP framework, include methodologies that are all typically labeled as active learning within the literature. However, the ICAP framework differentiates between types of behaviors in order to better analyze the effectiveness of different strategies on student learning. Hands-on activities as described in this paper primarily incorporate interactive and constructive behaviors in the learning process in order to maximize the depth of student learning.

It has become well-accepted in recent years that active learning strategies result in better learning outcomes than traditional lecture methods, as reported through hundreds of research studies and multiple meta-analyses [6], [9] – [11]. In the meta-analysis of 225 studies [9], implementation of active learning interventions in the design of STEM class sessions resulted in increases in student performance on examinations and concept inventories, as well as a decrease in failure rates versus classes with traditional lecturing models. The positive results across the literature led the authors to state, "If the experiments analyzed here had been conducted as randomized trials of medical interventions, they may have been stopped for the benefit-meaning that enrolling patients in the control condition might be discontinued because the treatment being tested was clearly more beneficial." [9]. While these findings are encouraging and confirm the imperative to implement active learning practices, the literature reviewed encompass a wide range in types of active learning strategies used and does not allow for analysis on the effectiveness of hands-on learning activities specifically.

Similarly, Ruiz-Primo and others [10] concluded that positive effects on student learning were evident when innovations involving active learning were implemented within undergraduate biology, chemistry, engineering, and physics courses. Studies in engineering courses only made up a small percentage (12%) of the final pool included in the analysis. In addition, the effect size in engineering courses (0.08) was substantially lower than those found in biology (0.54) and physics (0.59) courses and mildly lower than those found in chemistry courses (0.27). While the researchers classified the active learning methods discussed in the reviewed literature into four types of innovations, they did not indicate whether certain types or combination of types were more effective than others. The hands-on activities detailed in this current study would likely be classified as a combination of conceptually oriented tasks and collaborative learning activities types of innovations as defined in Ruiz-Primo et. al [10].

While the meta-analyses discussed above [9] - [10] highlight promising results about the effectiveness of active learning in comparison with traditional passive teaching methods, it is not possible to isolate the effects of specific active learning methods. The ICAP framework and related research findings suggest that interactive and constructive methods yield better learning than more simplistic active learning or passive learning methods [7], [12]. Thus, it can be inferred that hands-on activities requiring peer collaboration and construction of solutions, such as the ones detailed within this study, would have a greater effect on student learning.

Hands-on activities in STEM courses involve the use of problem-solving skills, quantitative/math skills, and integrative ability to utilize multiple skills sets acquired from other contexts [13]. Implementing hands-on activities as an instructional strategy in an astronomy course for non-science majors and in a calculus-based physics core course for engineering majors demonstrated a positive effect on student learning as compared to traditional lecture-based methods, as well as better student engagement and student retention rate [13]. While this study shows the promise of using active learning methods in STEM courses, it is quite limited in scope and does not explore engineering courses specifically. Catalano and Catalano [14] explored the shift from teacher-centered to student-centered engineering course designs and determined that student performance and retention rate both increased. They also comment that student-centered classroom practices appear to be most effective when in conjunction with technical depth, rather than as a substitute for such expertise. Catalano and Catalano [14] also outline seven instructor roles responsible for the shift to active learning which include many similar aspects as those used to design the activities explored within this study, such as knowing the actual and desired cognitive levels of activities, developing questions that facilitate student exploration and growth, using visual tools to establish connections, and providing group learning settings. These examples provide some insight into the influence of hands-on activities as a specific type of active learning on student learning in STEM courses. However, literature focused primarily on the effects of hands-on activities within engineering courses on student learning is quite limited. This study contributes to addressing the need for more research within engineering education on the impact of specific active learning methods.

Ability and confidence in independent learning are crucial for preparing students to transfer their knowledge and skills into new contexts [4]. In tackling active learning tasks, students have a genuine opportunity to experience a sense of accomplishment and empowerment as they achieve success as independent learners. Through these achievements, students prove to themselves their capability in figuring out how to find and use knowledge in meaningful ways to solve real-world problems, which in turn helps them to develop stronger confidence in their own abilities as learners [3]. Cech et. al. [5] performed a longitudinal study of undergraduate engineering majors and found that professional role confidence, the confidence individuals have in their ability to be successful in their intended profession, is significantly associated with both behavioral and intentional persistence through an engineering degree. Implementation of active learning strategies, including hands-on activities and group problem solving, in a sophomore level engineering course showed an increase in students' self-confidence with regard to their skills, abilities, and knowledge [16]. In addition, students reported a stronger interest in engineering and commitment to pursuing engineering as a profession following their completion of the course.

Development and Implementation of the Hands-On Experience

A series of hands-on activities titled Hands-On Wednesday (HOW) was designed and implemented throughout an entire statics course in an effort to improve student learning of Statics concepts. The goal of HOW is to give students the opportunity to develop a physical connection to and understanding of the course main concepts while improving expertise confidence in the material. Activities are designed to give students real-time, physical feedback that reinforces intuition and corrects misconceptions. This immediate feedback is designed to help students learn to defend their proposed solutions by giving them the opportunity to observe many different outcomes in a short period of time.

Hands-on activities are integrated into the course using a scaffolded method. In sessions occurring earlier in the term, HOW stations are direct physical representations of homework problems submitted the day before the session. In later HOW sessions, the students are given variations on the homework problems or brand-new problems to solve within the session. There are six weeks of sessions deployed over the seven-week term that cover the following topics: basic vectors, particle equilibrium, moments, free body diagrams, rigid body equilibrium, and trusses/machines and frames.

Each HOW session begins with a brief introduction to each of the two stations for that week along with general expectations. From there, students interact and experiment with the setups in various fashions while responding to technical and deeper thought-style questions. A typical 90-student course is divided into two, 45-student, 50-minute sessions. Students work in groups of five at each of the two hands-on stations every week of the seven-week term. To facilitate these sessions with 45 students at a time, five copies of each station are set-up within the room.

The overarching goal of each station is to take paper and pencil style problems off the page and into a mode where students can physically manipulate the problem constraints. Setups incorporate elements such as tape measures, scales, and torque wrenches, giving inexperienced students exposure to common tools used within the discipline. When students arrive at each station, they open an online worksheet that introduces the station and gives the individual station goals. These goals generally revolve around applying weights or other loads at various locations to measure a physical outcome such as force, distance, or torque. Students manipulate tools and components of the station setup and are able to explore the concepts physically through direct interaction. For example, when students adjust the angles of force vectors within the system, they will experience a difference in the tension present in their lines that are associated with that change in angle. These tactile experiences provide immediate feedback and visualization to the solutions they previously calculated on paper.

While students are interacting with the stations, they respond to questions through Canvas, the web-based learning management system used at Worcester Polytechnic Institute. These questions range from specific technical responses to fundamental underlying concept questions that require student groups to think more deeply about trends or effects of one part of a system on another. The technical questions guide student through the problem-solving process. The concept questions are designed to help students develop a deeper understanding of the material by connecting it to their physical understanding or thinking beyond the direct question posed.

Example Hands-on Stations

The following section describes two stations that utilize a 2-foot PVC cube structure, one piece of equipment developed for HOW. Approximately 15 different stations have been developed and deployed over the past 4 years in Introduction to Statics courses taught by multiple faculty at Worcester Polytechnic Institute. Two additional station examples that utilize different equipment are shown in Appendices B and C.

Cube in Space:

The statics course begins with a review of vectors and practicing using vectors to describe both forces and positions in space. These concepts lay the ground work for 3D particle equilibrium analysis as well as rigid body analysis. Students are often prepared to analyze vectors on paper using at least one method, but have a limited sense of what a force vector or position vector physically means. Without this fundamental understanding, students are ill prepared to apply their technical skills to systems they see in the world around them. The Cube in Space station helps build their intuition and understanding of length quantities and special relation.

This station is based on a previously assigned homework problem, see Figure 1, in which students are solving for the position vectors between multiple points in 3D space as well as the magnitudes of those vectors. For homework, students calculate position vectors and vector magnitudes. For the HOW activity, see Figure 2, the students are given the physical representation of that cube and are asked to measure the position vector magnitudes between the points they calculated for their problem set, see Figure 3. This station can be a re-creation of the exact homework problems where students set-up and measure previously calculated vectors, or new locations can be given for the students to both calculate and measure during HOW depending on student level, class size, and timing.

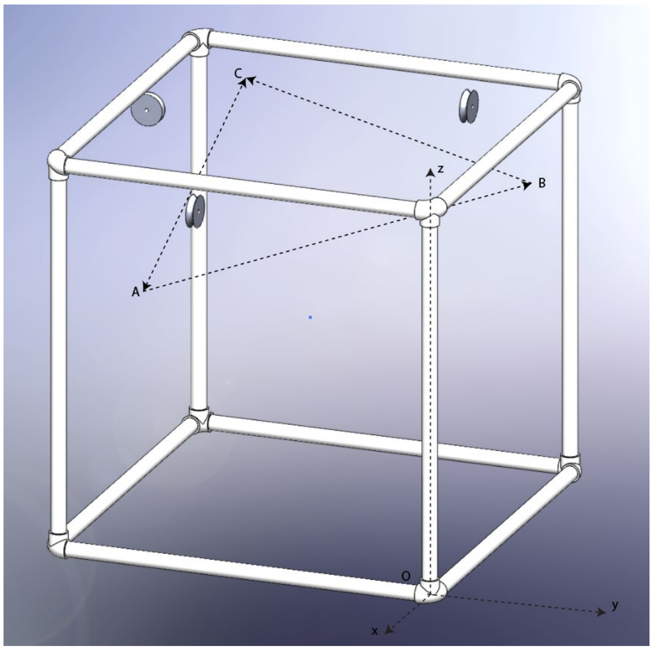
The first step when working on this station is to define an origin location and orientation on the cube. While this is an obvious set for someone with a thorough understanding of the engineering mechanics, many students do not think to look for, or define an origin. They are often initially too overwhelmed at the idea of having to take the physics from the page and recreate it in physical space to think through the concrete steps they would normally follow when solving on paper. Giving students a few minutes to struggle when starting this station helps them determine that one of their first steps when modeling a physical system is to define an origin in space. If they have not figured out that they need to find or identify an origin within a few minutes, then hints are often given. While measuring position vectors in space may seem like a simple exercise, students take time to make the connections between needing to identify an origin, locating physical points in space, determining methods to mark those points, and finally measuring the distance between the points. As this is one of the first stations deployed in the hand-on series, it is important to give time for those connections to be made. While they are very quick at solving the problem on paper, visualizing these points in space can pose a different type of challenge.

As this is a station in the first hands-on session in the course, student response questions are mostly centered around technical responses rather than deeper concept questions. The first three questions, shown in Figure 2, guide students through the steps of the station. These questions ask them to think about the homework they already solved, and then they compare their measured values to those calculated. In questions 4 and 5, students are asked to think beyond the questions asked on their homework and to think about the largest and smallest position vector magnitudes they can measure between points on the PVC sides of the cube. For the largest, students are generally quick to realize that they can measure between opposite corners on the cube. For the smallest, student teams often initially measure the length of one side of the cube. This makes for a great discussion point within the group, or with the instructor, to help the students see that a smaller vector can be measured if they measure between tubes that meet at a single corner. This results in the smallest measurable vector being based on the increments of the measurement tool.

This station generally takes 15-20 minutes to complete with 5-10 minutes remaining to respond to questions.

Given: a 3D PVC cube with 4 locations identified on the cube (O, A, B, C).

Based on those locations, calculate the position vectors between various points as well as the distances between those points.



The coordinates of the points in inches in terms of (x,y,z) are

O: (0,0,0) inch

A: (-4,-26, 12) inch

B: (-12, 0, 8) inch

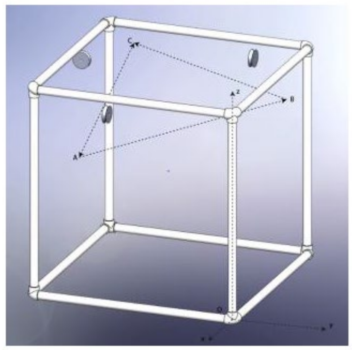
C: (-6,-21, 26) inch

Find: Calculate the following 4 vectors and their magnitudes (distance between the two points):

1) $\mathbf{r}_{AB}$ and r_{AB}
2) $\mathbf{r}_{AC}$ and r_{AC}
3) $\mathbf{r}_{CA}$ and r_{CA}
4) $\mathbf{r}_{BC}$ and r_{BC}

Figure 1 - Cube in Space – Homework Problem

In the “Cube in Space” homework problem you calculated 4 vectors and their magnitudes based on the labeled locations A, B, C, and O. For this station, you will be measuring these vector magnitudes using the 3D PVC cube, strings, and tape measures provided.



Answer the following questions to complete this station.

1. What were your calculated values for r_{AB}, r_{AC}, r_{CA}, r_{BC} from your homework?
2. What were your measured values for r_{AB}, r_{AC}, r_{CA}, r_{BC}?
3. List two reasons for the difference between your calculated and HOW measured values.
4. What is the largest position vector magnitude you can measure between points on the PVC cube?
5. What is the smallest position vector magnitude you can measure between points on the PVC on the cube?
6. Take a picture of someone from your group measuring one of the position vector magnitudes to upload on CANVAS.

Figure 2 - Cube in Space HOW Station – Input to CANVAS or Given on Paper for handwritten responses.

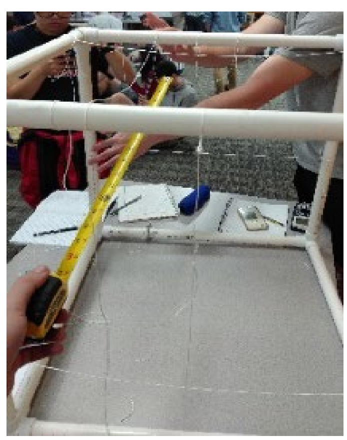


Figure 3 - Students measuring magnitude of position vector between two locations marked out with string on the cube.

Moments in 3D Cube:

About midway through the course students move on from particle analysis and begin to see how forces applied at different physical locations in space would make an object tend to rotate. They are not yet to the point of analyzing rigid bodies (i.e. not yet including $\Sigma M=0$). One of the skills integrated into a statics course is calculating 3D moments as well as moments about specified axes by calculating a scalar triple product. This can be a difficult concept for students to grasp due to the layered nature of the math involved.

This station, shown with the associated homework problem in Appendix A, gives students a visualization of the scalar triple product that occurs when you take the dot product of a vector moment. The torque wrench only measures moments in one direction, so they only measure that one value. The other components of the applied moment are not measured with the tool.

As this station takes place midway through the course, students are more efficient at solving problems in the physical space provided by these sessions. This increased level of student comfort allows students to think more deeply about the setups. At this station, after students recreate the setups described in their homework, students are asked to think of the ways in which the 3D moment effects a device that is designed to measure torque along one axis. This helps students visualize the ways in which each component of a moment vector effects bodies in different ways. Students are also asked to think beyond the given setup by determining the location of a force to maximize the moment reading on the torque wrench. By playing with the setup, students get immediate feedback as to the ways in which changing the force vector effects the dot product of the moment applied by the force. They eventually determine that the force vector should be perpendicular to and in plane with the torque wrench arm.

Evaluation and Assessment of Hands-On Experience

Assessment and Evaluation

The success of Hands-On Wednesday was assessed during the first term of 2019.

Methods

A mixed methods evaluation approach was designed to assess improvements in student learning and self-efficacy for those participating in the redesigned Introduction to Statics course. Of the 90 students enrolled in the course, 61% (n=55) participated in with complete pre- and post-course survey responses. Of participating students, 60% are underrepresented minority students (with one or more of the following identities: women, non-binary gender, Black, Latinx). The remaining 40% are white men. At the time of taking the course, 78% of participating students were in their second year of college, 14% were in their third year, and 8% were in their fourth year.

Data were collected using a retrospective survey. The Student Assessment of their Learning Gains (SALG) was administered at the end of the course to measure learning gains, attitudinal shifts, and the extent to which various aspects of the course contributed to these changes.

Students are asked to assess the extent to which each aspect of the course (e.g., attending lecture, Hands-On Wednesdays) contributed to their learning using a five point Likert scale from "no gains" to "great gains." These indicators of the quality of experiences allow analyses to correlate and isolate the effects of various aspects of course design.

The retrospective SALG has been used by more than 21,000 instructors to assess half a million students across the US in projects funded by the National Science Foundation under the Research Experiences for Undergraduates opportunity. The SALG was also constructed and validated with support from the National Science Foundation [17]. While self-reported measures have limitations, validation studies have led the developers to conclude that there is adequate fit between student self-report of their own learning and performance measures of learning. In fact, in one validation study, Gutwill found that among students experiencing unfamiliar forms of pedagogy, fewer students perceived that they understood the material well than those whose instructor-rated performance measures indicated competence in the material [15]. The tool therefore serves as a valid, reliable means of assessing student learning gains for the purposes of this pilot study.

Student responses were linked using an anonymous participant code generator for students to create a unique identifier they could easily recreate that would conceal student identify from the researchers. After assessing bivariate correlational relationships, multiple regression was used to estimate the effects of Hands-On Wednesdays and the quality of experience students reported on student learning outcomes, and student attitudes. A set of hierarchical regression models were constructed to compare the predictive power of Hands-On Wednesdays after controlling for student background and the extent to which attending lectures was beneficial to students.

Findings

When asked, "How much did Hands-On Wednesdays help your learning?," 10% of students reported that Hands-On Wednesdays were little or no help, 62% reported it was of moderate help, and 28% reported it was of much or great help. In comparison, 5% of students reported that attending lectures was little or no help, 15% reported it was of moderate help, and 80% reported it was of much or great help. To further examine the impact of Hands-On Wednesdays on student learning and attitudes, findings from hierarchical multiple regressions isolate the effects of Hands-On Wednesday.

Student Learning Outcomes. After controlling for student background and the effects of attending lectures, experiencing a high quality Hands-On Wednesday significantly predicts learning in five areas: understanding main concepts explored in class, understanding how studying this subject area helps people address real world issues, learning how to draw appropriate free body diagrams for given systems, learning how to develop a logic argument to defend a proposed solution, and learning how to work effectively with others (see Table 1).

Student comments on how they experienced Hands-On Wednesdays highlighted the utility of being able to visualize and manipulate conceptual problems. As one student shared, "The visualisation and actual doing things very much helped me internalize the concepts presented." Another student described, "I could visualize the bodies that were being used on the homework

Table 1. Summary of Predictors of Learning Outcomes and Attitudes in Introduction to Statics

	Model 1: Student Background		Model 2: Attending Lectures		Model 3: Hands On Wednesdays	
	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
Learning Outcomes						
Main Concepts	.01	.01	.41	.40*	.52	.11*
Relationships between Main Concepts	.03	.03	.30	.26*	.35	.05
Relating Statics Ideas to Other Classes	.04	.04	.26	.22*	.30	.04
Addressing Real World Issues	.03	.03	.22	.19*	.31	.10*
Identifying the Type of Problem	.02	.02	.19	.17*	.20	.01
Drawing Appropriate Free Body Diagrams	.02	.02	.14	.12*	.26	.12*
Defending a Proposed Solution	.13	.13*	.32	.19*	.37	.06*
Working Effectively with Others	.02	.02	.25	.23*	.37	.12*
Attitudes						
Enthusiasm for Engineering	.01	.01	.28	.27*	.33	.06*
Interest in Taking More Engineering Classes	.01	.01	.27	.27*	.36	.09*
Confidence in Understanding the Material	.05	.05	.30	.25*	.38	.08*
Confidence in Doing Statics Work	.03	.03	.22	.19*	.25	.04
Comfort Working with Complex Ideas	.03	.03	.23	.21*	.29	.06*
Willingness to Seek Help	<.01	<.01	.19	.18*	.23	.04

Note: n=55

assignments. [HOWs] were good in helping me understand the conceptual side of statics rather than just focusing on the math."

Several students also noted that Hands-On activities bridged the gap between mathematical procedures and conceptual understanding of the material. One student reported that, "HOW helped my learning when I had difficulty grasping concepts addressed in homework problems. When doing the homework, I realized that often times I was able to complete the analysis to find the answer, but wasn't sure how to write the explanation. HOW helped with that."

High quality Hands-On Wednesdays did not significantly predict learning in three areas after controlling for student background and the effects of attending lectures: understanding the relationships between main concepts, understanding how ideas from this class relate to ideas encountered in other classes, and learning how to identify the type of problem to be solved (e.g., particle vs. rigid body, 2D vs. 3D).

Student Attitudes. Experiences of high-quality Hands-On Wednesdays significantly predicted students' confidence in understanding the material and students' comfort working with complex ideas, even after controlling for student background and the effects of attending lecture (see Table 1). Increases in students' enthusiasm for engineering and interest in taking additional engineering classes was also significantly influenced by the extent to which students found Hands-On Wednesdays beneficial (see Table 1).

Barriers Indicated by Students. Students indicated that team dynamics was sometimes a barrier to their learning during Hands-On Wednesdays in their comments about this aspect of the course. One student, who otherwise indicated that Hands-On Wednesdays were quite helpful to her, shared that "It was helpful to actually see how things act in person, however my group seemed to do a lot of the work without completely including me on a few of them so it wasn't always the most helpful." Several other students mentioned managing team dynamics in their comments, indicating that students need scaffolding on how to reap the benefits of teamwork.

Discussion and Conclusions

The goal of this course redesign was to implement a series of hands-on activities that would give students the chance to better connect to the core concepts and gain confidence in the content presented in an Introduction to Statics course. Students report that the series of weekly hands-on sessions, supplementing a traditional lecture course, added to their understanding of main course concepts taught in the course while increasing their confidence and enthusiasm for the subject. Further examination of student learning gains will be needed to confirm that these self-reported learning gains correlate with improved performance, vis a vis course grades, persistence to degree, and other outcomes associated with improved learning.

While this study has shown significant positive outcomes to the implementation of a high-quality Hands-On Wednesday experience, the study is currently limited to the evaluation of a single implementation in a single instructor's course at a small private school. In this study, students reported that a high-quality hands-on experience had no effect on helping students connect content from this course to that taught in other courses. However, as most students in the

Introduction to Statics course are in one of their first engineering courses in their curriculum, they have not had many opportunities to connect Statics content to other courses. A longitudinal study would be required to learn more about the relationship between the effects of a hands-on experience with connecting content from different courses. A longitudinal study could also be helpful in analyzing the effects of and hands-on experience and students' abilities to identify the type of problem being solved in a more general context outside of a Statics course.

The constraints of small sample size due to studying a single instance of a course limits the number of statistically significant bivariate correlational relationships that can be identified. With continued data collection, other relationships that will be analyzed include effects of URM status, effects of the quality of the hands-on experience, dosage effects of hands-on activities, and replication in other courses and/or at other universities.

Currently, several other faculty members at Worcester Polytechnic Institute have deployed the series of hands-on activities in their Introduction to Statics courses using names such as Hands-On Learning Days (HOLD), Hands on Monday, and Firsthand Friday. Data has yet to be collected and/or analyzed from these other courses.

Instructor Tips

Below are some tips that have been helpful throughout the terms running this series of hands-on activities.

- It is ideal to have a teaching assistant or undergraduate helper to set-up and run the stations with you. That way each person has one station and can float amongst the groups there.
- Give the students time to think about the stations before jumping in and helping, but if they still are not sure where to start after about 5 minutes, they may need a hint.
- The setups are not designed to perfectly align with the calculations that the students complete on paper. This is a great opportunity to help students see the ways in which we make assumptions when modeling physical systems. They will learn quite a bit about friction!
- The students may need help tying knots with the string used in various stations. Be sure to practice your knots. The figure eight and bowline are particularly helpful!

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Appendix A – Example of Hands-On Activities: Moments in 3D Cube

Below is the homework representation of the Moments in 3D Cube problem. In addition to seeing the included graphics, students will have already seen the physical cube during the first hands-on session. If the earlier hands-on session is not run, the cube should be brought to class before the homework is due for students to see the general shape and size of the setup.

Moments in 3D Cube - Homework Problem

A single weight is attached to a torque wrench with a cable at point E. A torque is applied is applied at point D and the component directed along a line parallel to the y-axis is measured using a torque wrench. Calculate this torque measure by the wrench for each of the following three cases; first the weight goes over pulley A, then the weight goes over pulley B, and then finally the scenario when the weight goes over pulley C. Solve for a 2 lb weight.

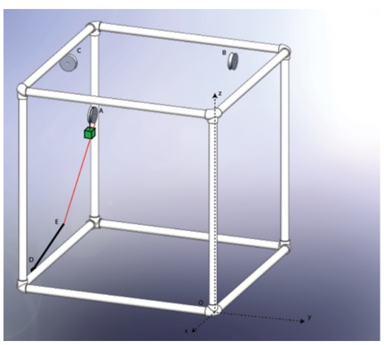
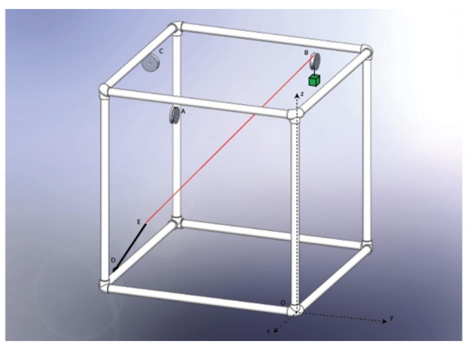
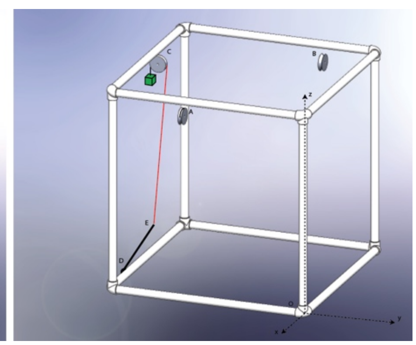
$\mathbf{r}_{OA}$= - 1$\mathbf{j}$ + 2$\mathbf{k}$ ft

$\mathbf{r}_{OB}$= -2i - .5$\mathbf{j}$ + 2$\mathbf{k}$ ft

$\mathbf{r}_{OC}$= -1$\mathbf{i}$ – 2$\mathbf{j}$ + 2$\mathbf{k}$ ft

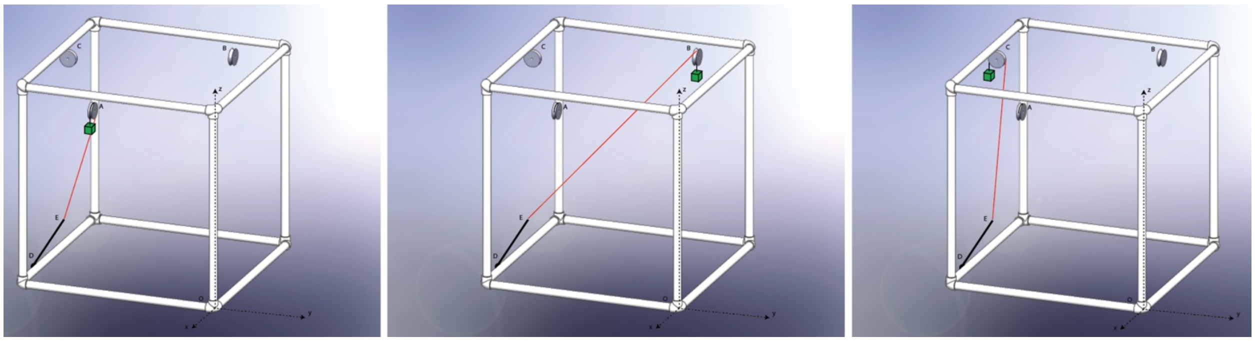
$\mathbf{r}_{OD}$= -.25$\mathbf{i}$ – 2.25$\mathbf{j}$ ft

$\mathbf{r}_{OE}$= -.89$\mathbf{i}$ – 2.25$\mathbf{j}$ + .24$\mathbf{k}$ ft

Moments in 3D Hands-on Station

This station is similar to your homework problem in which you calculated the moment measured by a torque wrench located at point D based on three different force vector scenarios.



$\mathbf{r}_{OA} = -1\mathbf{j} + 2\mathbf{k}$ ft

$\mathbf{r}_{OB} = -2i - .5\mathbf{j} + 2\mathbf{k}$ ft

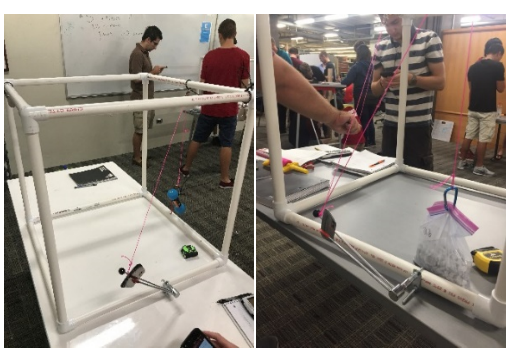
$\mathbf{r}_{OC} = -1\mathbf{i} - 2\mathbf{j} + 2\mathbf{k}$ ft

$\mathbf{r}_{OD} = -.25\mathbf{i} - 2.25\mathbf{j}$ ft

$\mathbf{r}_{OE} = -.89\mathbf{i} - 2.25\mathbf{j} + .24\mathbf{k}$ ft

Setup the station to simulate the three problem set scenarios.

1) What moments do you measure with the torque wrench?
2) List 3 reasons for the differences between your measured values and your calculated values. (Note: listing "human error" is a general statement that does not clearly define your situation. Be specific in defining your errors.)
3) How did the torque wrench physically deform when it was loaded with moments that were not the intended direction for measuring use? I.e. how did the moments about the other two axes affect the tool?
4) Where would you apply the weight in 3D space to generate the largest measured moment on the torque wrench?



Students applying a 3D moment at the base of a torque wrench by applying a force vector to the handle via a string/pulley/weight system.

Appendix B – Example of Hands-On Activities: Particle Equilibrium

The second major topic cover in a statics course is static particle equilibrium. This topic involves students using the vector skills they learned/practiced earlier in the course and adds the static equilibrium condition. This example station gives students the chance to work with weights, pulleys, and strings to achieve a specified balance point. Students first complete a homework problem where they calculate an unknown distance and an unknown force to achieve a vertically balanced pole. For the hands-on station, students recreate this balance scenario. The immediate feedback of "does it balance" or not allows them to see the effects of different force magnitudes and positions.

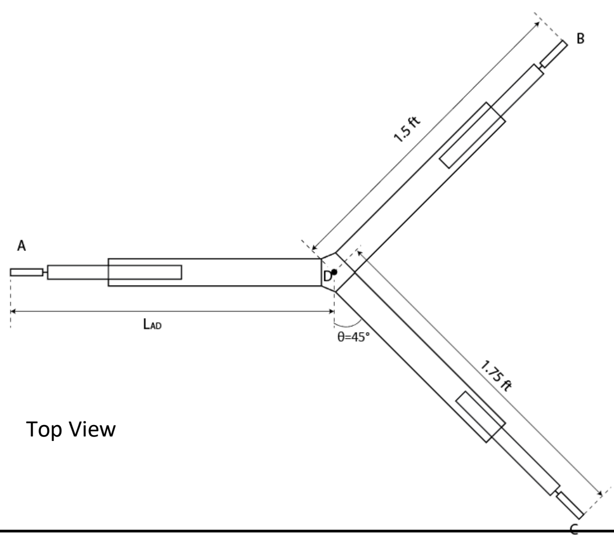
Pole Balance Homework Problem

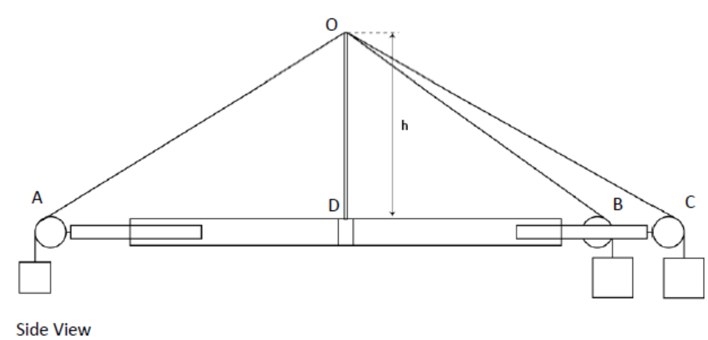
You will be balancing a pole on a platform at point D with the tension of three cables (OA, OB, and OC) using the setup shown below. Determine L_{AD} and F_{OB} (weight hanging over pulley B) required to hold the pole in a vertical position.

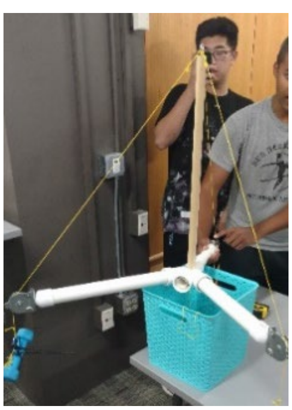
F_{OA} = 5 lb

F_{OC} = 2.5 lb

h=2 ft



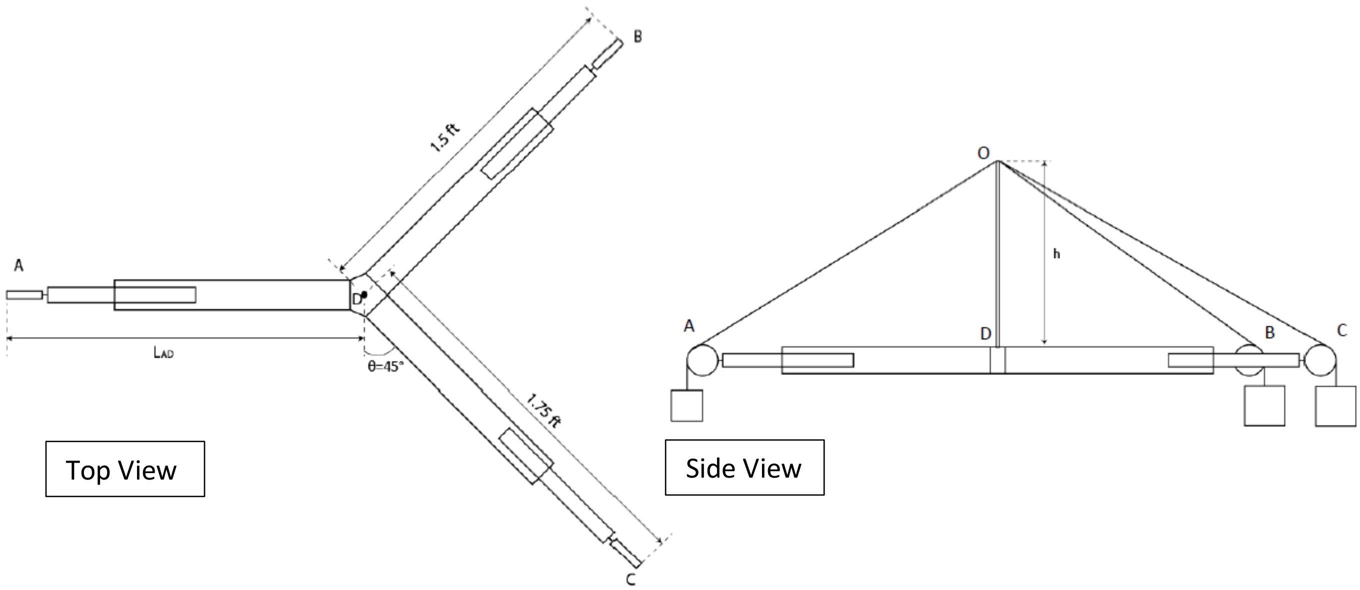




Students with pole balanced on the PVC wye.

Hands-on Pole Balance Station

This station is based on your previous homework problem. You will be building and testing the pole balance that you solved in your problem set. You will be balancing a pole on a platform at point D with the tensions of three cables (OA, OB, and OC) using the setup shown below. Determine L_{AD} and F_{OB} (weight hanging over pulley B) required to hold the pole in a vertical position. Recall: $F_{OA} = 5$ lb, $F_{OC} = 2.5$ lb, $h = 2$ ft.



Answer the following questions:

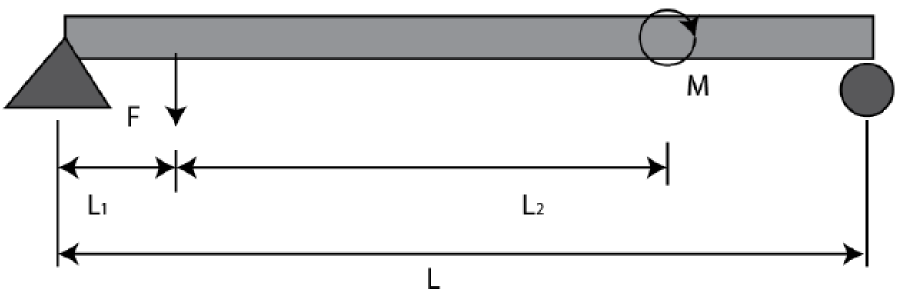
1) What weight did you use at pulley B and what length did you use to L_AD (this should be what you solved for on your homework)?
2) Did this weight and length allow the pole to balance vertically when centered at point D or did you have to move the pole away from the exact center point to get it to balance? Explain why your calculated values did, or did not, allow you to balance in the center of the PVC wye.
3) What is the vertical force acting in pole OD?

Appendix C – Example of Hands-On Activities: Rigid Body Equilibrium

This station is not a re-creation of a previously submitted homework problem. At this point in the term, students are faster at working through the stations, so adding calculations is a great way to have them think through the math in the same space that they experiment. The students work at whiteboards to solve for reactions before applying the force (with a weight) and the moment (with a digital torque wrench). Reactions are measured with digital scales. It is important for students to apply as pure a moment as possible to get results that will align with their calculations.

At this station, you will be calculating the reactions for the system below for the configuration shown. Once you have calculated the reactions, test the system to determine how your calculated versus measured values compare.

Complete this analysis twice. Once neglecting the weight of the beam and a second time including the weight of the beam.

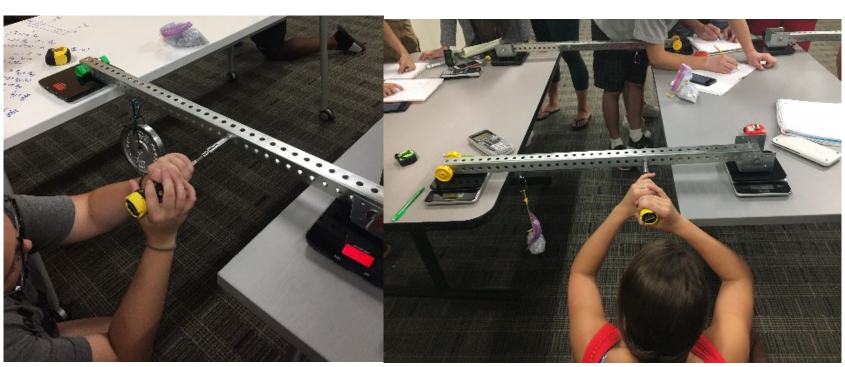


M = 30 in-lb

F = 5 lb

Answer the following questions:

1) What were your calculated answers for the reactions at the pin and the roller when you did not include the weight of the bar?
2) What were your calculated answers for the reactions at the pin and the roller when you did include the weight of the bar?
3) What were your measured answers for the reactions at the pin and the roller?
4) Explain whether or not you should neglect the weight of the beam for the scenario analyzed.



Students applying a 30 in-lb couple moment to the beam structure. The 5 lb force is applied by a plate weight or a bag of weights. Scales on the ends of the beam measure reaction forces.