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CRI: Hands-on activities designed to enhance comprehensive understanding of Statics concepts

Prof. Chaitanya Krishna Prasad Vallabh, Stevens Institute of Technology (School of Engineering and Science)

Prof. Chaitanya Krishna Prasad Vallabh is currently a Teaching Assistant Professor in the Department of Mechanical Engineering at Stevens Institute of Technology. His research interests include Advanced Manufacturing, Additive Manufacturing, Engineering Education, and Machine Learning Applications in Manufacturing and Automation.

Dr. Vallabh is also a Center for the Integration of Research, Teaching and Learning (CIRTL) certified STEM teaching associate. He is interested and passionate about engineering education research and would like to develop evidence based teaching methodologies for STEM education.

Dr. Maxine Fontaine, Stevens Institute of Technology (School of Engineering and Science)

Maxine Fontaine is a Teaching Associate Professor in Mechanical Engineering at Stevens Institute of Technology. She received her Ph.D. in 2010 from Aalborg University in Aalborg, Denmark. Maxine has a background in the biomechanics of human movement, and she currently teaches several undergraduate courses in engineering mechanics. Her research interests are focused on improving engineering pedagogy and increasing diversity in engineering.

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Abstract

Certain concepts in Statics have been traditionally challenging for students to completely grasp and implement them successfully. Lectures and example problems help reinforce and strengthen some of these concepts. However, these problems often primarily address the mathematical framework of the problems and do not foster an intuitive grasp of the underlying concepts. For students to achieve true mastery, it is essential that they develop both the ability to visualize problems and a fundamental understanding of the concepts before approaching their mathematical solutions.

To help facilitate this kind of intuitive learning and understanding, we have developed a series of hands-on lab activities targeting certain important topics in Statics, namely, Moment of Force, Support Reactions and Equilibrium, Free Body Diagrams (FBDs). These activities are specifically designed to help students engage directly with these fundamental concepts, allowing them to better visualize and understand the concepts more clearly.

The Statics course (ENGR 211 – Statics and Introduction to Engineering Mechanics) offered at our university, Stevens Institute of Technology, is taken by all engineering majors, including mechanical engineering, civil engineering, biomedical engineering, computer engineering, software engineering, and electrical engineering. This broad representation underscores the need for instructional approaches that are effective for a diverse group of learners. As students come from various engineering backgrounds, the implementation of hands-on activities becomes especially important. These activities are designed to address the differing levels of familiarity and experience that students may have with Statics concepts. The primary focus of these developed lab activities is to enhance students' qualitative understanding of Statics concepts, rather than simply emphasizing quantitative problem solving.

To gauge the efficacy of the lab activities we conducted a brief survey with 179 participants, and the results showed a promising positive trend in student understanding of the assessed concepts. Future work will focus on quantitative statistical evaluations of the surveys and improving/ expanding these activities.

Introduction

Engineering statics is a foundational course often regarded by students as conceptually difficult and theory heavy in its instruction [1]. It is evidently pointed out in the literature that mathematics is rarely the primary issue in problem solving, but it is the missing physical-world to theory connection which is the primary reason why students find it difficult to master Statics [2], [3]. One such example is the construction of free-body diagrams (FBDs) [4], students often find it difficult to get the right solution to problem because their FBD is incorrect, this is also observed by Brose and Kautz [3]. This gap in conceptual understanding can lead to poor performance and retention issues in engineering programs [1], [6]. To address this gap, we added hands-on lab activities to improve the cognition of certain Statics concepts, namely, moment of a force, moment arm, FBDs, and support reactions. We also implemented lab activities to strengthen the concepts of zero force members and trusses; due to the nature of this CRI paper we are reserving the discussion of those activities for future dissemination.

Studies have shown that hands-on activities, such as using simple models to demonstrate vector addition or moments, can improve student engagement and learning outcomes [1], [7], [8]. The development of low-cost, portable modeling kits has been shown to improve "representational competence" the ability to navigate between physical systems and graphical models. Implementation of these kits in Statics instruction has shown to improve the learning competency of the students [7], [8], [9]. Further, projects such as the construction of spaghetti or balsa wood bridges, serve as a synthesis of structural analysis and design [10], [11]. The literature suggests that traditional lecture-based instruction coupled with the integration of hands-on lab activities or projects is very helpful to bridge the gap between theory and physical real-world intuition in engineering Statics.

In this CRI paper, we will discuss the "hands-on" lab activity implementation for improved learning and concept retention in moments, and FBDs. We will also briefly discuss their success, backed by student surveys. The implemented lab activities primarily focus on the qualitative cognition of concepts rather than the quantitative aspects, that is, the mathematics of the problem. For instance, in one of the activities, students are asked to use the long and short handles of an Allen wrench to loosen a bolt. We then ask the students to qualitatively report which scenario was easier and which one was harder.

The lab activities were completed in the lab section associated with the lecture section; each lab period is 110 minutes of duration. The labs are primarily run by the TAs; however, the instructors introduce the lab, discuss the activities in detail, answer any associated questions, and monitor the lab activities while the TAs handle the one-on-one troubleshooting. TAs receive orientation and training for each lab activity. These activities are accomplished using an assembled engineering kit, which consists of a structural engineering kit (Thames & Kosmos Structural Engineering: Bridges & Skyscraper), 3D printed components, dumbbells, and an Allen wrench. The price of this developed kit is expected to be around $50 (bulk order price is expected to slightly lower), which is feasible for implementation in Engineering Statics course.

Methods

Moment of a Force lab activities:

Students manipulate the moment arm length when loosening a bolt to physically "feel" the varying force required to generate a moment. See Figures 1 and 2

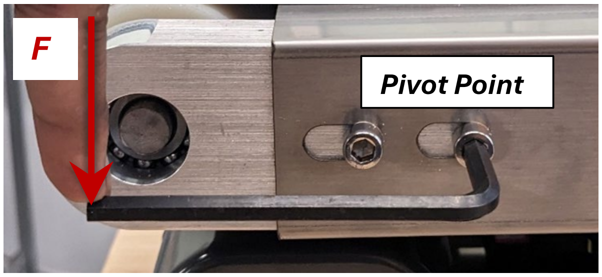


Figure 1: Scenario 1 - using the longer end of the Allen wrench.

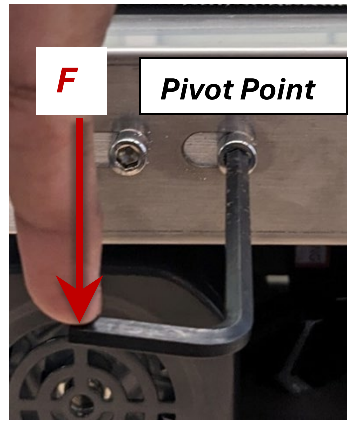


Figure 2: Scenario 2 - using the shorter end of the Allen wrench.

Following this activity, students are asked to answer these questions in their individual submission:

"Questions:

1. *Is the **moment** required to loosen the screw in Scenario 2 greater, less than, or equal to that in Scenario 1?*
2. *Is the **force** required to loosen the screw in Scenario 2 greater, less than, or equal to that in Scenario 1?*
3. *If the required forces were not equal, estimate how many times greater or smaller the required force would be. (Hint: Measure the moment arm distance for each case.)* "

Following this activity, students are asked to perform a bicep curl using a dumbbell and answer the following questions. Students choose the dumbbell weight of their liking and comfort.

"Questions:

1. *At approximately which elbow angle(s) was it most and least difficult to hold the dumbbell? The elbow angle is defined as the angle between the forearm and upper arm as shown in Fig. 3.*

2. *Does the bicep force act to rotate the forearm clockwise or ccw during the exercise?*

3. *Does the weight of the dumbbell act to rotate the forearm cw or ccw during the exercise?*

4. *Does the **moment** required to hold up the dumbbell remain the same throughout the motion?*
5. *Does the muscle **force** required to hold up the dumbbell remain the same throughout the motion?"*

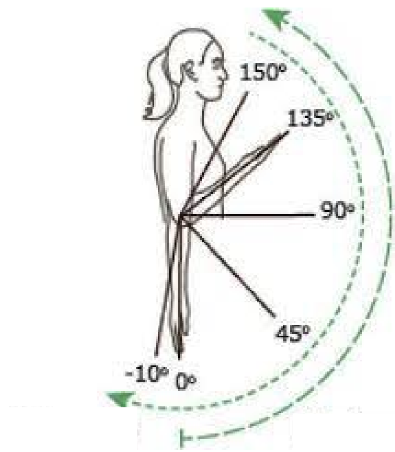


Figure 3: Schematic showing elbow angle. [Source: https://core.ac.uk/download/pdf/157691516.pdf]

Moment arm activity:

In this lab activity, students are asked to construct a partial truss structure as shown in Figure 4. The forces F_1, F_2, and F_3 represent the internal forces acting along the respective structural members.

Students are provided with the following instructions for completing the lab activity students: *"hold the lower left corner of the truss to represent the pin support. Then apply each of the three forces as shown in Figure 4 by gently pulling the appropriate truss member, one at a time. Observe how applying each of these forces affects the overall truss structure."* After the activity, students are asked to answer the following questions in their report:

"Questions:

For each of the three forces, answer the following two questions:

1. *Does this force act to rotate the truss clockwise or counterclockwise about the pin support?*
2. *What is the moment arm for this force about the pin support? Draw a diagram of the partial truss structure and clearly indicate the moment arm."*

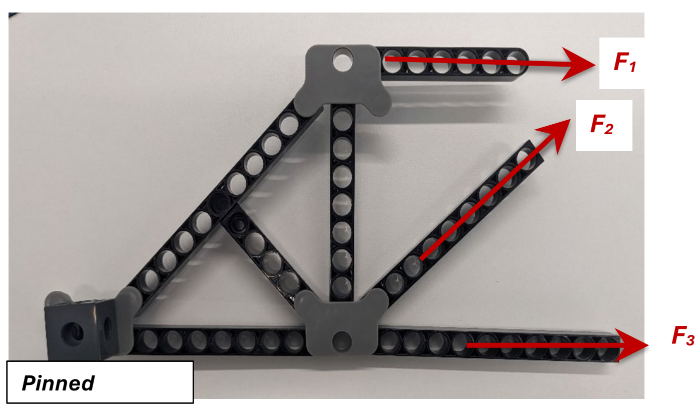


Figure 4: Partial truss structure built using the Structural Engineering kit.

Support Reactions & FBDs lab activities**:**

Using the provided kit and materials, students construct physical models with supports including pins, links, rollers, and fixed supports to hold a plate in equilibrium. They then translate these physical systems into corresponding FBDs. Figure 5 shows a representative structure with the supports. Students are provided with the Frame to support the plate.

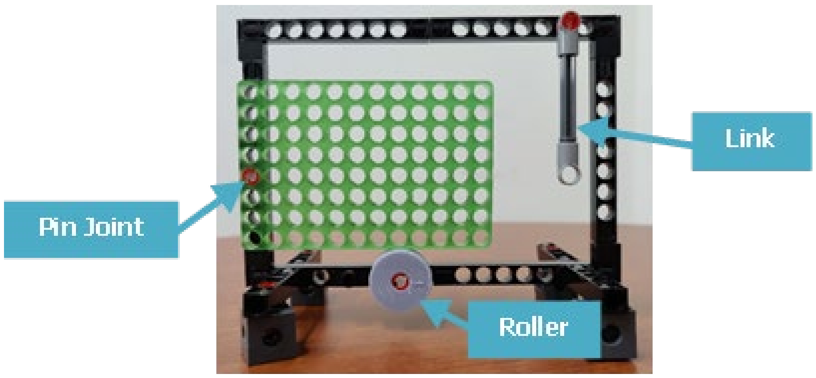


Figure 5: Representative physical frame to hold the rectangular plate in equilibrium using supports. A link is shown in the Frame as an example for students.

These are instructions provided to the students for completing the lab activities:

Create multiple designs for a system to support the 3D printed rectangle (Fig. 5) in the horizontal position and in the same 2D plane as the built frame.

- *All designs should include the minimal number of supports needed to satisfy the constraints, i.e. no statically indeterminate systems / no redundant supports.*
- *All designs must also be UNIQUE, i.e. no two designs can be identical.*

For each design, you will draw the free-body diagram and take a photo of your physical build. For every challenge, you will create two different design solutions.

Survey Results

A brief survey was conducted at the end of the semester to understand the effectiveness of the implemented lab activities. Following an IRB and taking research participation consent from the students, we were able to get a total of 179 responses. The questions were framed following a 5-point Likert-type scale style. One representative question is shown below:

"How clearly did the lab activity help you understand the concept of the moment of a force?

a. ***Not at all clearly – The lab did not help me understand the concept.***

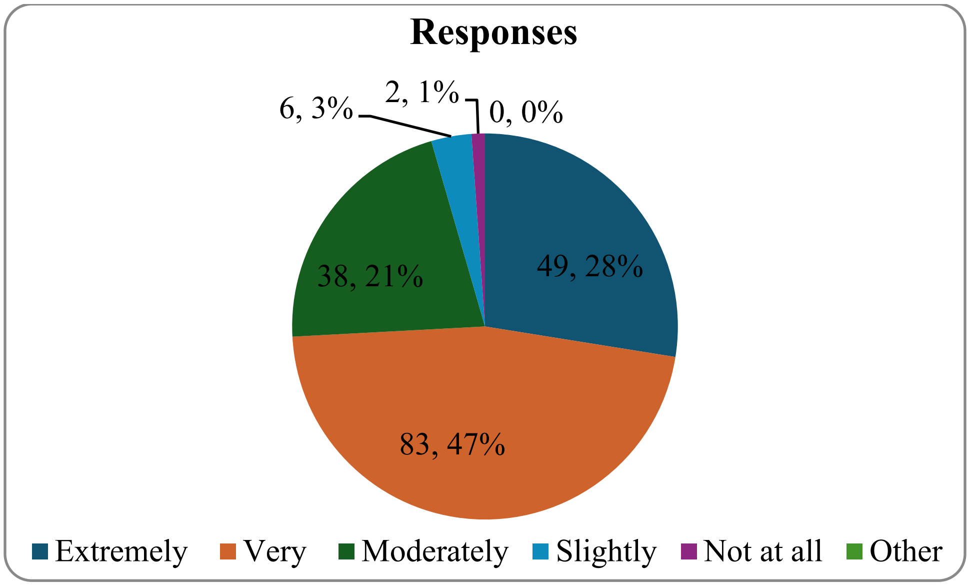
b. ***Slightly clearly – I gained a little clarity but still find the concept confusing.***

c. ***Moderately clearly – My understanding improved, but I need more practice.***

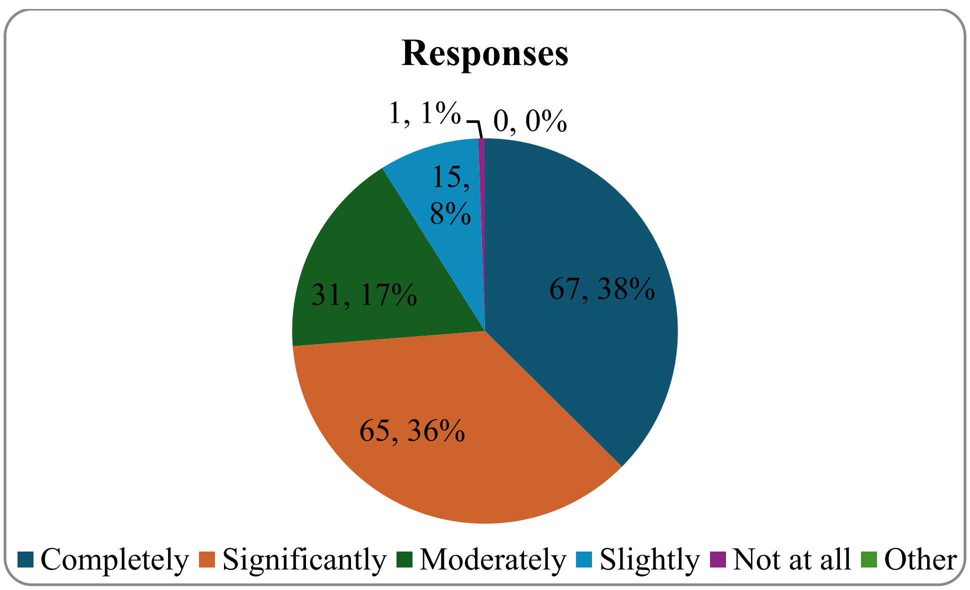
d. ***Very clearly – I now have a much clearer understanding of the moment of a force.***

e. ***Extremely clearly – I fully understand the concept as a result of this lab.***"

The survey responses to the questions are shown in the following Figures, Figure 6 consists of all questions relating to the Moments lab activities, and Figure 7 addresses the Supports and FBD lab activities. The pie charts show the number of respondents, and the corresponding percentage.

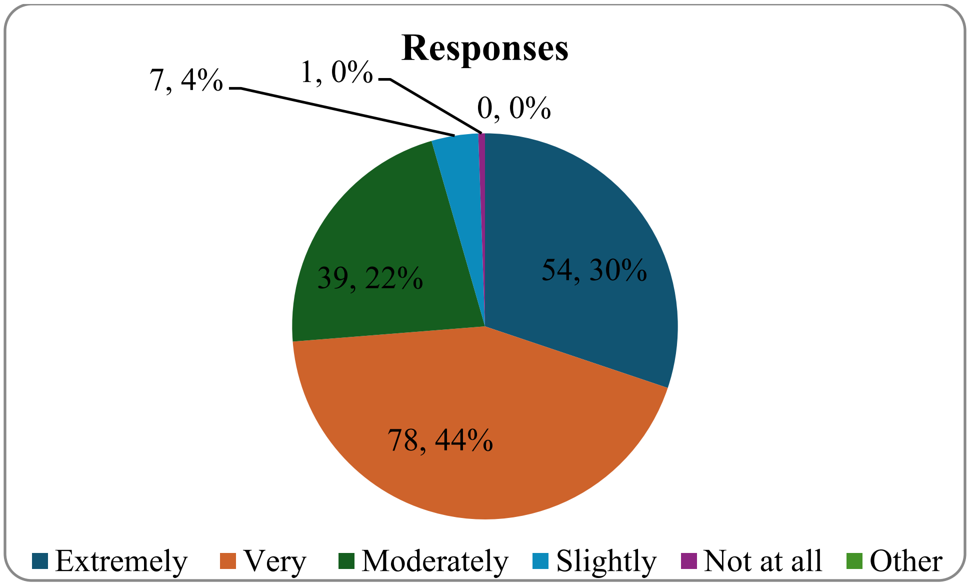


(a) how clearly did the lab activity help you understand the concept of the moment of a force?

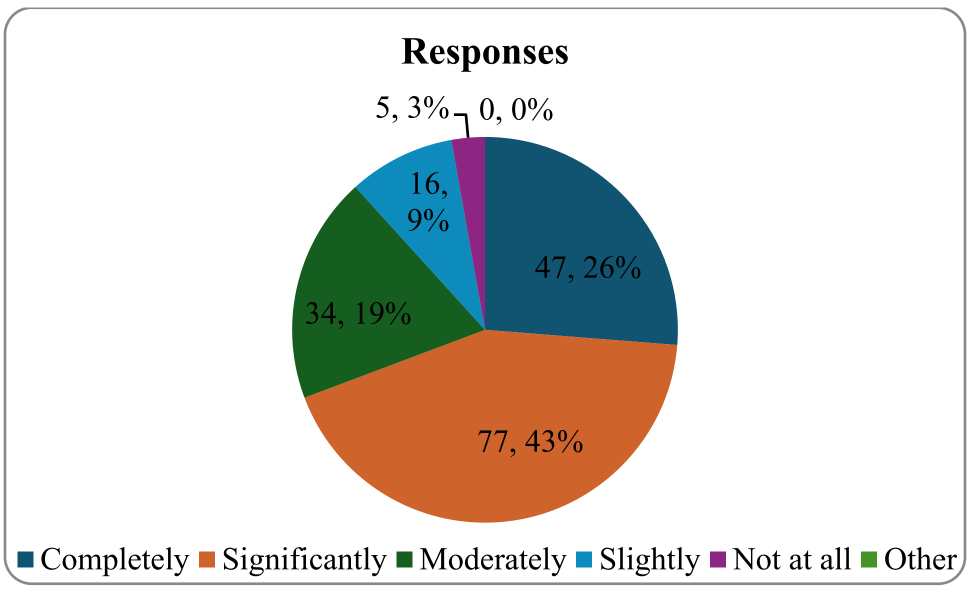


(b) did the lab connect the theory of moments to real-world applications in a meaningful way?

Figure 6: Student Responses (n = 179) to the survey questions regarding the effectiveness of the moments lab activity



(a) how confident do you feel in identifying different types of supports and their corresponding reactions after completing this lab?



(b) to what extent did the lab improve your ability to draw support reactions in free-body diagrams?

Figure 7: Student Responses (n = 179) to the survey questions regarding the effectiveness of the FBDs and supports lab activity. The pie chart shows the number of respondents followed by the corresponding percentage (n, %) for each category.

Discussion and Conclusions:

As shown in Figures 6 and 7, the majority of the students, i.e., 70% and above, indicated that their understanding of moments, FBDs and supports has increased Very/ Significantly or

Extremely/Completely for the respective lab activities. For brevity, the authors are reserving the detailed survey for a future paper. The detailed survey is expected to show the correlation of the hands-on lab activities to student learning and longitudinal knowledge retention. Therefore, these results strengthen the argument of including “hands-on” activities in an Engineering Statics course.

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