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Identification and Creation of Experiential Learning Modules for Engineering Statics and Dynamics (Work in Progress)

Anthony Battistini

Dr. Anthony Battistini is an Assistant Professor in the David L. Hirschfeld Department of Engineering at Angelo State University. His expertise is in structural design, with an emphasis in steel bridge structures and connections. "Dr. Batts", as his students call him, aspires to provide students with a quality and enjoyable experience in the classroom. He is actively engaged in improving the quality of education across the country through his participation as an Assistant Mentor in the ASCE ExCEEd Teaching Workshop as well as making classrooms more equitable through his participation as a Facilitator for the ESCALA Certificate in College Teaching and Learning in HSIs and the ESCALA Culturally Responsive Teaching in STEM Mini-Course for HSIs. To get more ideas for demonstrations and how to introduce themes to your classes, Batts encourages you to check out his YouTube Channel (search Dr. Anthony Battistini) and his other ASEE conference papers.

Mohammad Shafinul Haque

Assistant Professor of Mechanical Engineering at Angelo State University. I teach fundamental and upper-level mechanical engineering courses including Senior Design. I enjoy interactive teaching with hands-on project-based learning.

Steve Guzman

Matt Sims

Matthew Sims is a Mechanical Engineering student with the David L. Hirschfeld Department of Engineering at Angelo State University. His work history and military service provided him with a working knowledge of mechanical and hydraulic systems, which now aids him in creating practical designs as he applies theoretical equations and builds CAD prototypes. Matthew seeks to advance his education and professionalism by taking advantage of the research opportunities at Angelo State University. His goal is to pass the Fundamentals of Engineering (FE) exam prior to his expected graduation of Spring 2023, so that he may enter the profession as an Engineer in Training (EIT).

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Abstract

Engineering mechanics courses in statics and dynamics are the first courses in engineering programs where students must combine concepts from mathematics and physics to real-world scenarios. As such, students enrolled in these courses often struggle to fully comprehend problems, particularly involving forces as two- and three-dimensional vectors in Cartesian space. Moreover, Latinx students typically associate with higher context cultural frameworks and prefer active learning strategies and group activities.

The project outlined will use hands-on experiential learning in engineering mechanics with the intent to improve student comprehension and retention, particularly for Latinx students at a Hispanic Serving Institution. To begin the project, the authors have developed an adaptive 3D coordinate model to facilitate hands-on experiential problem-solving in group laboratory sessions. In addition, they have conducted a survey among faculty and students to identify the most troublesome concepts in Statics and Dynamics. Using the results of the survey, experiential learning modules will be created to include these concepts.

The following paper will document the results of the survey, the development and design of the adaptive 3D coordinate model, and will outline at least one experiential learning module for Statics and one for Dynamics. A proposed assessment plan to measure comprehension and retention of engineering students taking these courses will be included.

Motivation

Engineering mechanics courses are the fundamental courses for mechanical and civil engineering students that build the foundation to be able to analyze and design a system that is at rest (Statics) and in motion (Dynamics). From designing a simple ladder to the formulation of a space shuttle trajectory, a deep comprehension of these core courses is required. Thus, these courses serve as a prerequisite for many upper-level engineering courses in most universities; however, a high drop-out rate in Statics and Dynamics is widely reported [1], [2].

In Mechanics, students have to deal with theories and problems of motion and to apply combined concepts from math and physics. Topics include 2D and 3D vectors, moments, trusses, geometric aspects of bodies under motion (kinematics) and the effect of forces on motion (kinetics) for particles and rigid bodies. Concepts such as static equilibrium, relative motion, the moment of inertia, and rotation are difficult (if not impossible) to explain with a 2D image or verbal explanation [3]. Often students describe their struggle as “I don’t know where to start” or “I read the problem, but I did not get it” [4].

Over the past five years, the David L. Hirschfeld Department of Engineering at Angelo State University has internally examined the DFW rate (percentage of total students receiving a grade of D or F or withdrawing from a course), particularly in foundational courses typically taken in the students’ first two years of the program. Table 1 summarizes the results for both Statics and Dynamics.

Following the completion of Statics and Dynamics, most students go on to successfully complete the Bachelor of Science degree requirements for the engineering program(s). Therefore, it is imperative for the continued success of the program(s) to increase retention amongst students taking these courses, forming the impetus for the proposed changes documented within this paper.

Table 1: DFW Rates for Engineering Mechanics Courses at Angelo State University

Course ID	Subject	DFW Rates by Fall and Spring Semesters									
		F 2017	SP 2018	F 2018	SP 2019	F 2019	SP 2020	F 2020	SP 2021	F 2021	Total
ENGR 2301	Statics		22%	48%	45%	59%	16%	36%	28%	12%	33%
ENGR 2302	Dynamics		12%	27%	8%	13%		28%	31%	11%	18%

Research suggests that using hands-on equipment for engineering mechanics courses facilitates active learning and significantly improves comprehension of engineering mechanics problems [4] - [14]. Over the years, several learning approaches have been proposed using hands-on equipment such as the “engage (see-feel-practice-apply) strategy”, “experimental problem solving”, “guided discovery”, and “inquiry-based learning” [10] - [13]. Recently, an integrated “experiential learning” that includes all these modes of learning is reported to be effective for knowledge acquisition [15], [16].

Moreover, as a Hispanic Serving Institution (HSI), the faculty researchers in this project feel an obligation to particularly increase the performance of the Latinx engineering students in the department. While active learning strategies have been well accepted to increase learning amongst all students, research shows that these active learning strategies and group activities are learning modalities typically preferred by higher context cultural frameworks with which many Latinx students typically identify [17] - [21].

For reference throughout the paper, Latinx is a term that has been increasingly used to describe populations from Latin American origins regardless of race, gender, or country of origin, with the “x” replacing the gendered Spanish endings of “o” or “a” to be inclusive of nonbinary gender identities [20]. Additionally, for the purposes of this research, the definition of a higher context cultural framework, also referred to as an integrated cultural framework, means that students “interpret the world in a highly contextualized manner, conceptualizing and interacting through interrelational connections and considering everything within an interdependent whole [18].”

Background

Wang Ken defined "Learning" as the process of entering into the experience of pleasure, and pleasure is the state of being brought about by what you learn [1]. Experiential learning is the process of learning by inquiring about the nature of experience [1]. Kolb stated that *experiential* learning includes all modes of the learning cycle and ensures effective knowledge acquisition [1]. Experiential learning includes four modes: Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE). The concrete experience and active experimentation can be achieved by hands-on experience of a physical model followed by a recording of experimental observations and measurements. Afterwards, students should reflect on these observations, facilitated by guided questioning, and then connect their observations to the derived theories (abstract conceptualization). Students can then actively perform additional experiments to test their new understanding. Nakazawa applied this approach to the engineering mechanics course by introducing different physical models for statics and kinetics [16]. Vernon developed a device named interactive-Newton (i-Newton) to facilitate experiential learning for dynamics. The i-Newton is a miniature sensing unit that can be attached to any object to measure acceleration and angular velocity, allowing students to observe and measure forces in small-scale dynamics tests and compare to theoretical calculations [22].

Several teaching modules are reported as effective for implementing experiential learning in mechanics, including a single semester-long project, small project(s) targeting specific concepts, and co-op work [5], [6], [21], [22], [23]. Unfortunately, a single project or co-op work may only cover a few course concepts, while targeted projects for each course concept is often unrealistic due to the time restriction and budget requirements. Therefore, an adaptive, interactive, hands-on 3D coordinate model is proposed by the authors to feature all four processes of experiential learning and to be implemented in weekly recitation or lab periods, allowing coverage of the full range of topics for the course. There are at least three concurrent research endeavors reported in the year 2020 involving 3D systems as shown in Figure 1 [7], [8], [24]. The application of these units is limited to coordinate accuracy (Figure 1a); or applicable only to positive (x, y, z) axes (Figure 1b). Moreover, forces and vectors acting in opposite directions (180 degrees) cannot be explained using these systems as they do not have the option for parallel planes (Figure 1c). Additional research endeavors reported with very limited application exist [9], [14], [25]. An improved model is needed.

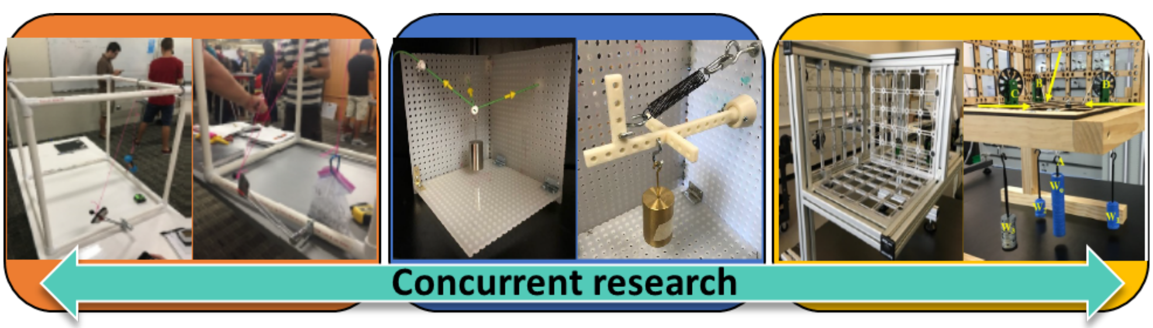


Figure 1: Concurrent research in other universities [7], [8], [24] (a) PVC-pipe cube, (b) Pegboard panel coordinate system, (c) Aluminum extrusion frame and wood structured units

3D Coordinate Model

The Experiential Learning in Mechanics (ELM) team at Angelo State University proposes the development of an improved 3D coordinate model to recreate various textbook problems in a three-dimensional space for engineering mechanics courses. This will allow students to better contextualize more complex physical systems for mechanics through experimental setups, preventing miscommunication between instructor and student as to what a system is experiencing (Concrete Experience), observation of explicit functions of a system (Reflective Observation), measurement of each component (Active Experimentation), and verification of results while also providing an opportunity to create systems of their own for analysis (Abstract Conceptualization).

For the general design of the model, a wire-frame cube was determined to be the most universal and the most manufacturable "3D space". The cube gives the model structural rigidity, making it less likely to deform under different experimental loading. Additionally, it allows the connection of multiple units to create larger, three dimensional spaces for classroom demonstrations and problems requiring multiple Cartesian octants. The T-slot aluminum extrusions selected to form the frame of the cube offer other benefits as well, such as the ease of customizing experimental setups using simple pieces that can be easily manufactured, 3D printed, or purchased.

For the scope of the project, there are 8 individual 3D test units, all of which are made with the same dimensions and assembly process, with the freedom and ability to configure in various ways. Each unit will be referred to as a "3D Module". The idea is that the 8 separate systems will allow 8 groups of students to work independently during course lab sessions or recitation periods, while the modularity of the system allows student groups flexibility and creativity when conducting experiments. However, these 8 modules can be brought together to assemble one large 3D system comprising the 8 octants corresponding to the permutations of +/- x, y, and z coordinates. A larger unit is highly beneficial for classroom demonstration to allow students to see from a distance or allow more students to gather around the unit, depending on the size of the course.

The ELM team envisions the construction of a specialized cart to move the 3D cubes to the classroom and to neatly store the units and all the individual experimental tools and experiential learning modules. This cart would act as the mobile "workstation", complete with a place to hold the models themselves, as well as the accessories that students will use. Accessories and components will be separated into various organizers for groups to use during each module.

Member Selection

When selecting members for the 3D unit frame, the team considered the following:

- Modularity- the ability of the one 3D unit to model a range of both statics and dynamics problems.
- Adjustability- the ability to move freely in various coordinate directions to emphasize the 3D nature of many engineering concepts.
- Ease of Movement- the ability to facilitate movement for dynamics-based problems.

It was ultimately decided that a rail and channel system would be the best to employ for the frame of the model. Aluminum extrusions were the prime candidate, as they provide a number of benefits such as ease of machining, corrosion resistance, and relative lightness as compared to steel, while still maintaining adequate rigidity for the structure. Each extrusion has a square profile, and on each side of every extrusion there is a T-shaped channel to allow the use of fixtures of varying styles to slide along the axis of the extrusion. This freedom of movement allows students to set up various dynamic problem situations (most of which are covered in a typical textbook) in a 3D space in order to better visualize them. The selection of extrusion for the frame also made construction simpler. 3D printed corner cubes with their own special extrusion mates create a mechanical lock between each segment in every axis direction.

Extrusions are a good foundation for additions to the model in the future. If measurement equipment needs to be mounted, or if an instructor decides to pursue motorization to model moving systems in 3D space, the extrusions provide a track in which to do so. The changeability, as well as aftermarket support and additional module development for these types of parts and systems means that these units can be used by various engineering mechanics courses in order to allow students an observable and ideally, measurable model for various learning modules.

SolidWorks Model

To help design the units, the team used SolidWorks CAD (computer aided design) models to visualize the systems and to verify geometric constraints. The original CAD models were created to give inspiration as far as visualization of the 3D space, as well as provide information about tolerances between parts. Still, prototypes of each of the customized module parts are developed first in CAD to ensure good tolerance. The SolidWorks models are shown in Figure 2 and Figure 3, and the current prototype of the single unit is shown in Figure 4.

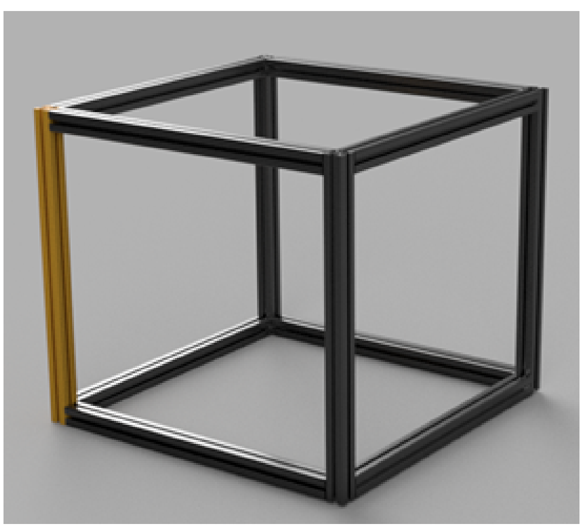


Figure 2: 3D Rendering of Single Unit

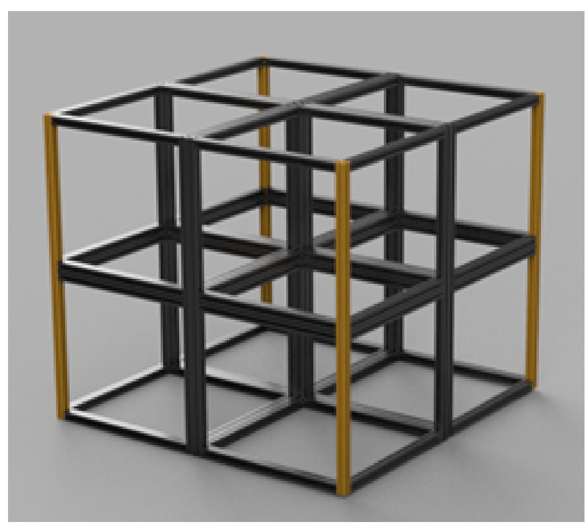


Figure 3: Full Assembly of All 8 Units

Figure 4: Prototype Unit

Prototype

Using the CAD model as a guide, the assembly of the first prototype unit was straightforward. The ends of each extrusion were tapped. A corner joint was modeled to mate to three extrusions. On the opposing face from each mate, an access point is provided to allow the joint to be connected to the extrusion using a screw (see Figure 4 and Figure 5).

All corners were 3D printed using PETG (polyethylene terephthalate glycol) for its ease of printing and rigidity. One property of PETG to note is the ability to fracture under excess loads without shattering. This was considered important as repairs would need to wait until lab sessions were completed so as not to disrupt the students' learning experience. The SolidWorks rendering and images of the printed corners are shown in Figure 5 and it is envisioned the PETG joints will be suitable for the final design.

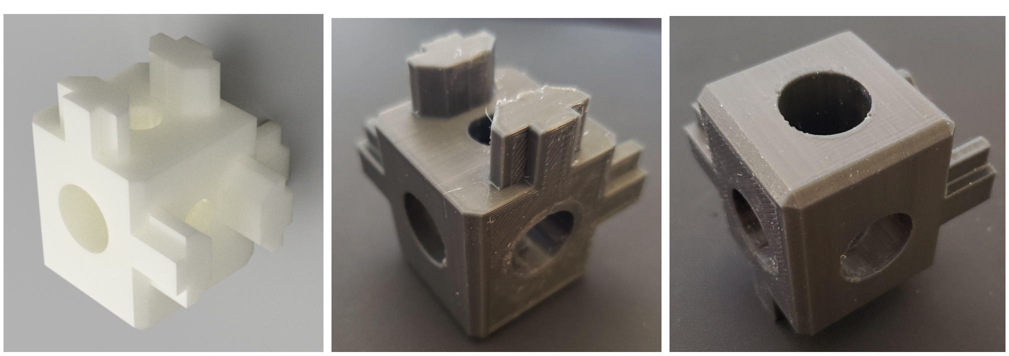


Figure 5: Corner Joint- (a) SolidWorks Rendering (b) Front Isometric View of 3D Printed Joint with T-locks and (c) Rear Isometric View of Joint with Access Points for Screws

Additional Elements

Where possible, the ELM Team will incorporate the use of “off-the-shelf” attachments for ease of replication by other instructors wanting to create similar 3D units and experiential learning modules.

- Carabiners: These will be employed to allow users to connect cables quickly.
- Key Rings: The rings create the idealized node, allowing forces to intersect at a “point”.
- Force Meter Spring Scale: These mechanical measurement devices allow students to observe and record applied forces in units of Newtons.
- Weights: Hanging weight sets for each unit include a 10 g, 20 g (2 x), 50 g, 100 g, 200 g (2 x), 500 g, and 1000 g weights.
- Custom 30 mm x 30 mm rolling flanges with set screws: Allow students to set a fixed position if needed.
- Pulleys: The team has acquired various types of pulleys to accommodate both statics and dynamics problems. The pulleys and related components are shown in Figure 6.

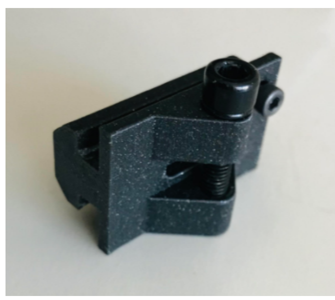
Description	**Part Image**	**Description**	**Part Image**
Pulley Hanger (3D printed in-house)		Double Tandem Pulley	
Dual Groove Pulley		Triple Groove Pulley	
Triple Tandem Pulley		Clamp Pulley	

Figure 6: Available Components for Future Problem Development

- Custom 3D Printed Supports: Used to match the idealized boundary conditions often assumed in Statics and Dynamics problems (such as the ball and socket swivel joint seen in Figure 7).

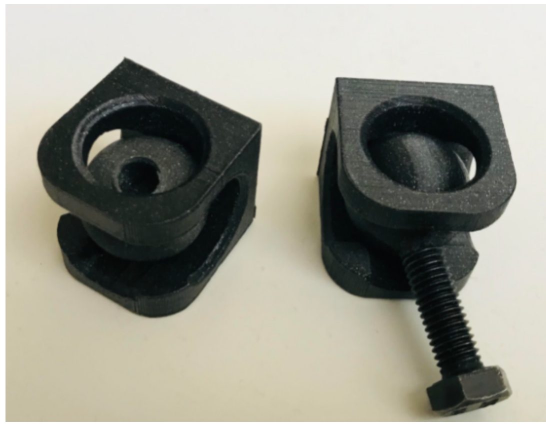


Figure 7: Ball and Socket Swivel Joint (3D printed in-house)

Angelo State University Survey

The ELM team sought to identify the concepts from Statics and Dynamics that students at Angelo State University have the most difficulty learning based on student perception and performance on assessments. Therefore, the team developed a survey to serve two purposes. Firstly, the survey could prioritize the development of the models for various statics and dynamics modules based on input from students and instructors. Secondly, the survey can act as a more recent resource for any future research conducted over these subjects.

Survey Questions

Questions and course topics included in the survey were selected through an iterative process amongst colleagues on the ELM team, with the help of other educators within the institution. A review of textbook topics also assisted in the isolation of course topics [26], [27]. The objective of the survey was to get a clear understanding of the most difficult concepts in engineering mechanics courses in order to maximize the effectiveness of experiential learning lab modules for students due to the limited laboratory sessions available in one semester.

The survey is focused on obtaining a student perspective regarding the most difficult course topics, but also included education professionals in order to capitalize on their regular experience of teaching the concepts in the classroom. The survey was distributed via email using a Google form link, with conditional settings to skip questions in which the recipient self-identified as not having relevant experience (i.e. if the student had not taken dynamics yet, the student was not asked to rank the dynamics topics in order of difficulty). For this reason, the ELM team wanted to know who was being surveyed, and what relevant experience or educational background they may have. The survey was sent to currently enrolled engineering students (junior/senior level) at Angelo State University who have successfully completed the Statics or Dynamics courses within the previous two to three years.

The full list of questions is:

- Are you an Instructor or Student?
  - Instructors
    - Do you teach Statics?
    - What is your typical class size?
    - Rate each topic according to difficulty level (1-least challenging, 5-most challenging)
    - Do you teach Dynamics?
    - What is your typical class size?
    - Rate each topic according to difficulty level (1-least challenging, 5-most challenging)
  - Students
    - Have you taken Statics?
    - Rate each topic according to difficulty level (1-least challenging, 5-most challenging)
    - Have you taken Dynamics?
    - Rate each topic according to difficulty level (1-least challenging, 5-most challenging)
- Do you have any comments/concerns to add?

Angelo State University Survey Data- Respondent Classification

Figure 8 through Figure 14 summarize the results for each question from the respondents at Angelo State University. Using the data, the ELM team has prioritized research activities to develop learning modules for the most critical topics.

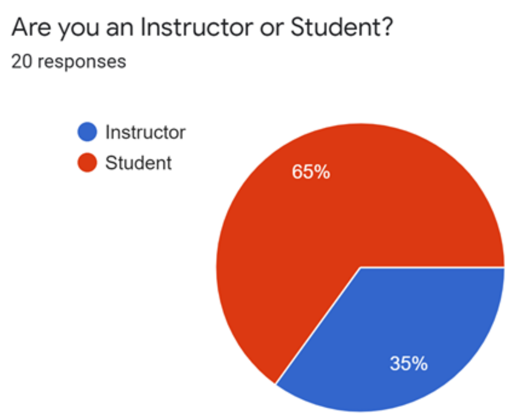


Figure 8: % of Student vs. Instructors

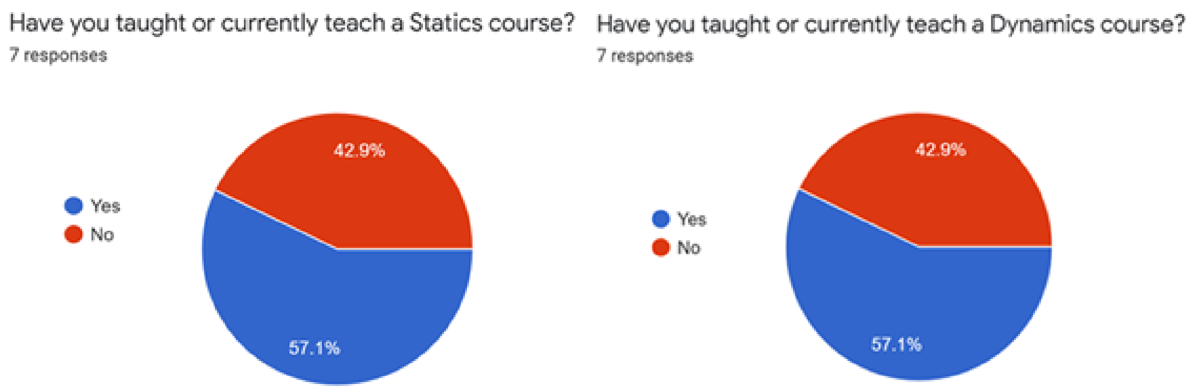


Figure 9: Clarification of Instructor Experience

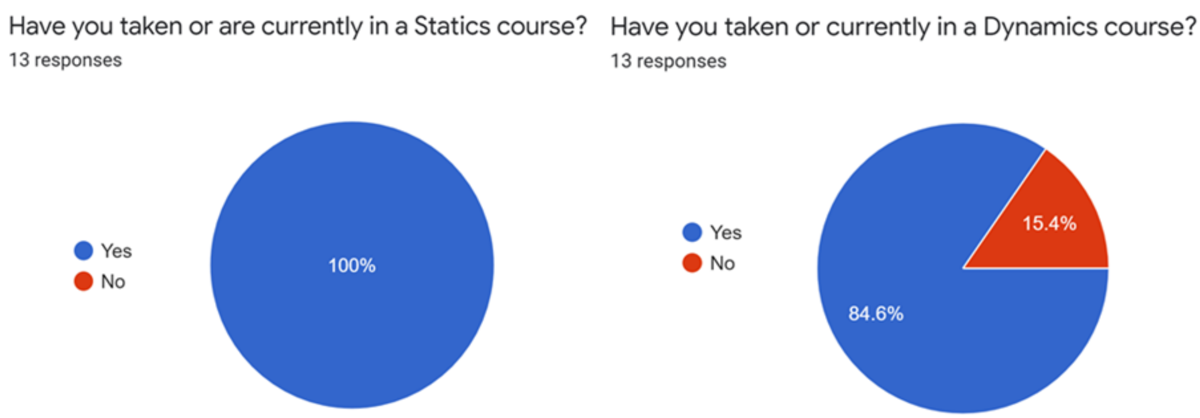


Figure 10: % of Students with Past Experience

Angelo State University Survey Data- Topic Difficulty

There were two major categories of survey questions. Statics and Dynamics. These two major categories were then further separated to distinguish student surveys from instructor surveys. This resulted in four sets of relevant data. Examples can be seen in the figures below. In order to keep this report a reasonable length, only a few examples of data are shown in the body of the paper. The complete data set can be found in Appendix B and explored in greater depth.

The ranking scale ranges from 1- least difficult to 5- most difficult, and includes Not Covered if a particular course does not cover the topic.

Student Questionnaire Data: A total of 11 students are represented in the Statics survey data and 13 students in the Dynamics data.

Rate the following Statics concepts according to difficulty to understand.

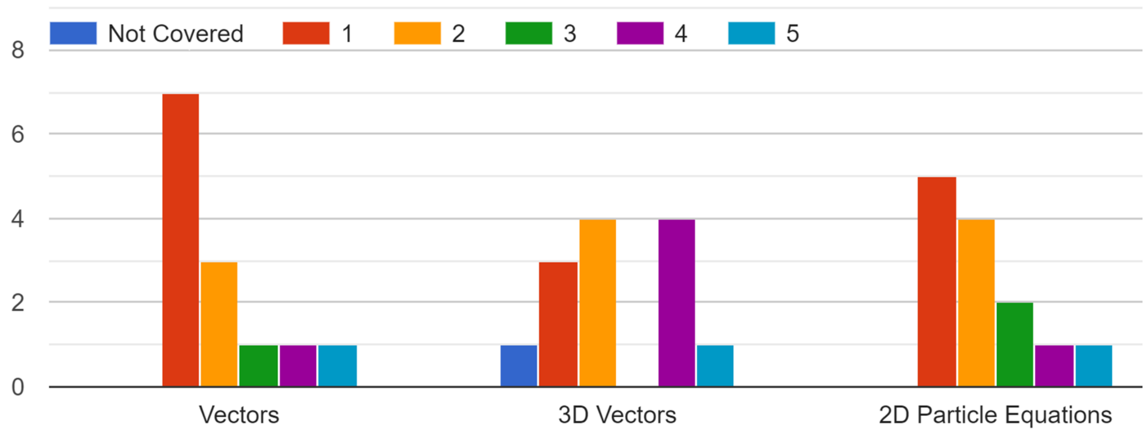


Figure 11: Student- Statics Data

Rate the following Dynamics concepts according to difficulty to understand.

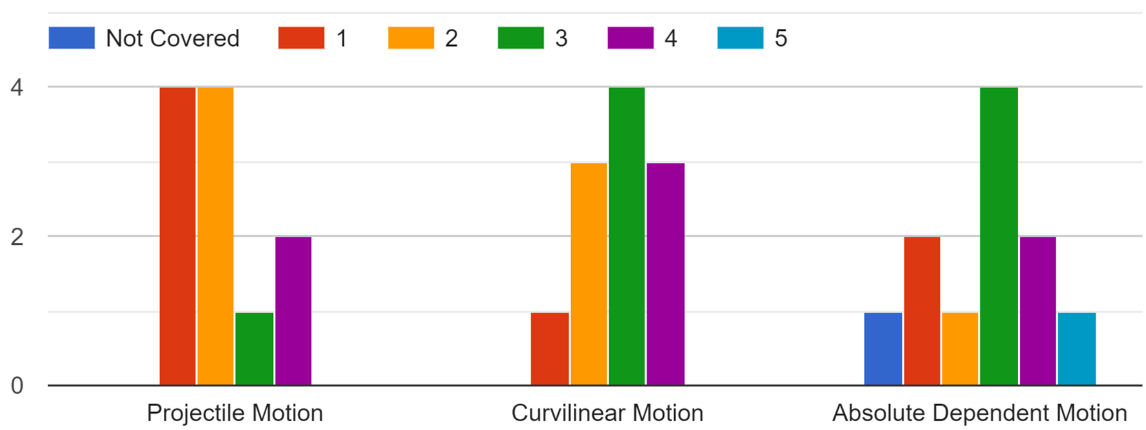


Figure 12: Student- Dynamics Data

Instructor Questionnaire Data: To date, a total of 4 instructors are included in the data collection.

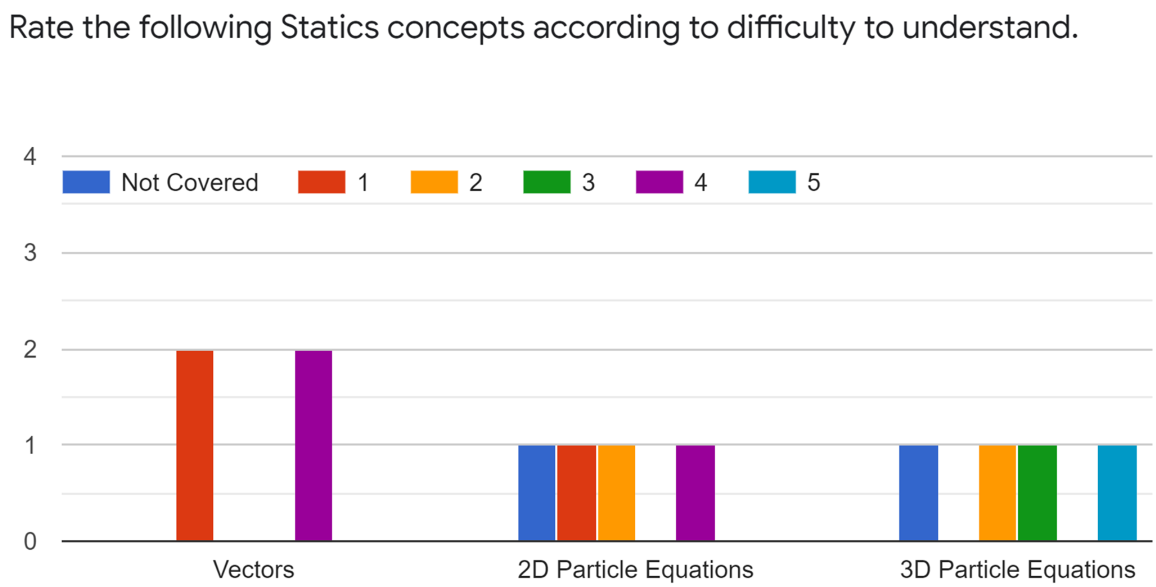


Figure 13: Instructor- Statics Data

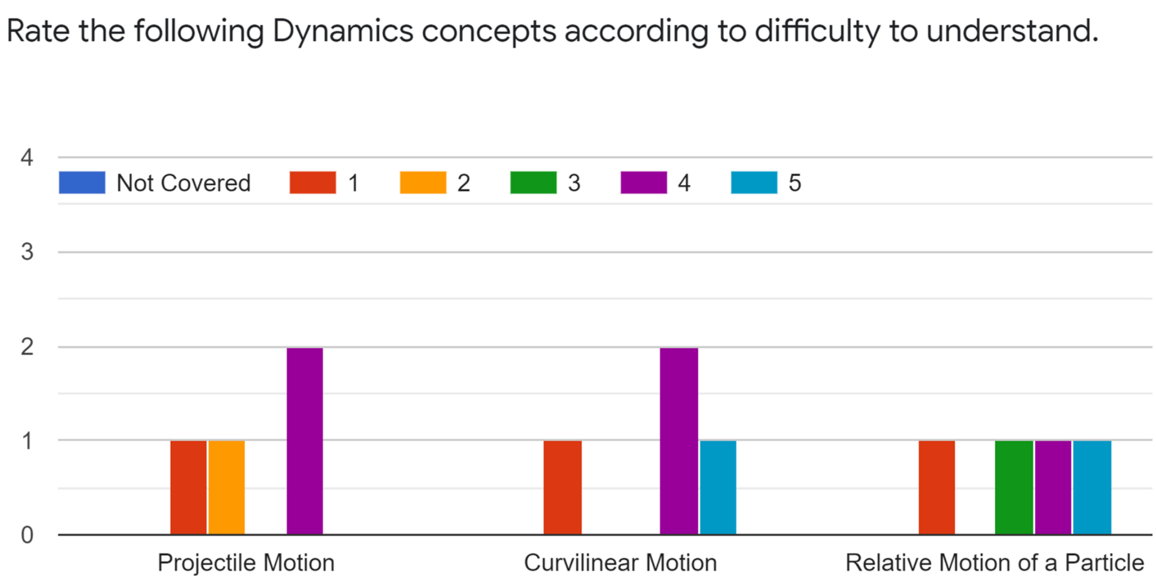


Figure 14: Instructor- Dynamics Data

Based on the data obtained, it is observed the results are varied by topic and dependent on people's experience and knowledge level within these subjects. Still, some very clear outliers have been noted regarding certain topics within each respective course where the majority of students at Angelo State University tend to struggle. Any topics with high green, purple, or light blue bars indicate that people tend to struggle with those concepts. This is very useful information for problem and learning module development, as it gives the team the ability to create experiential learning modules tailored to meet the needs of the students at the university.

It is important that instructors at HSIs specifically incorporate more integrated cultural framework activities to appeal to their general demographics [18], [20], [21]. Often, instructors tend to identify more with individuated cultural frameworks (or have at least navigated the U.S. higher education system and are adept at operating in this cultural framework) and therefore do not readily incorporate activities that appeal to students from an integrated cultural frameworks [20]. The ELM team hopes the experiential learning modules developed through this project will appeal to students from both backgrounds and help to improve comprehension and retention of students at HSIs.

Statics Learning Module

The Statics Learning Module is meant to illustrate the various topics throughout a typical statics mechanics course by engaging students through the active assembly and operation of developed problems. The problems are intended to mirror problems seen in typical textbooks. For the purposes of the project at Angelo State University, the learning modules are developed to be completed in one, 50 minute recitation period currently used for supplemental problem solving practice with the instructor.

For an introductory problem and proof of concept, the use of a planar two cable problem was selected to be the first Statics learning module created. The complete module is available in Appendix C. The following summary identifies how it addresses the aspects of experiential learning:

- Concrete Experience: In Task 1, students are asked to assemble a 2D cable problem supporting a hanging weight and to observe the force measured by each spring force gauge and compare it to theoretical calculations.
- Reflective Observation: In Task 1, students have to calculate percent error to determine if the measured forces match the theoretical calculations. Task 2, requires the students to reflect on their observation by answering the guided questions listed.
- Abstract Conceptualization: Task 2 requires students to make a prediction about how the forces would be affected if the cable angles change. In addition, the Questions section asks for students to predict the behavior of the cable forces as the weight applied changes. Students should be able to use the theoretical and physical models to inform their conceptualization.
- Active Experimentation: In Task 2 and the Questions, students can perform additional experiments to validate their predictions.

Dynamics Learning Module

The dynamics learning modules are generated based on selected textbook problems. A worksheet was developed that includes four tasks that will facilitate experiential learning and hands-on problem solving as shown in Appendix D:

- Concrete Experience: In Task 1 the students are asked to assemble a pulley-block system similar to the textbook problem and observe the motion of the blocks and maximum traveled distance.

- Reflective Observation: In Task 2, the students have to reflect on their observation by answering the guided questions listed. The instructor reviews their answer and discusses any errors before moving to the next step.
- Abstract Conceptualization: The first two tasks facilitate the abstract conceptualization of the theory of potential energy and kinetic energy. In Task 3, the students are required to relate their observations in Task 2 to derive the equations for potential and kinetic energy. The instructor guides the students to develop the principle of work and energy, assuming no energy loss. Students apply the principle of work and energy equation to determine the theoretical maximum traveled distance and compare with the test performed in Task 1.
- Active Experimentation: At the end of Task 3, students are ready to perform additional experiments and validation. In Task 4, a modified problem is given and the students have to perform tests and apply the principle of work and energy to solve and validate their solutions.

Proposed Assessment Plan

A. Participant Information

Approximately 80 undergraduate engineering students will be enrolled in the Statics and Dynamics courses for Fall 2022 and Spring 2023 at Angelo State University, and all will be recruited for the survey. The students will be asked to rate the hands-on 3D Cartesian coordinate system that is used in the Statics or Dynamics course, answer a few short questions about the 3D system, and propose any comments to improve the system. Participation will take less than 10 minutes, and students may receive 10 bonus points (equivalent to one daily quiz point) for the course. Participants' signed consent form will be kept in the locked office of the PI. The survey will be paper based and the information gathered in this survey will be presented only in aggregate without any information to personally identify participants and of only those who sign the consent form. All data will be maintained for at least three years after completion of the study.

B. Survey Measures

The survey will be performed in the last week of Fall 2022 and Spring 2023 semesters seeking students' feedback and preference of experiential learning compared to the traditional approach. The exam results and course evaluation will be compared with the past couple of semesters to measure improvement in passing rate. The total number of As, Bs, Cs, Ds, Fs, and Ws per semester, gender, race/ethnicity will be collected and compared; no personal identifying information will be collected.

Sample questions for the survey:

Select between (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree) for the following statement:

a) The hands-on problem solving session using the 3D coordinate system is helpful in visualizing engineering theories.

b) The hands-on problem solving helped me better comprehend the Statics or Dynamics concepts than traditional lecture courses or written problem solving sessions.
c) The hands-on problem solving was interesting, fun and engaging for me.
d) I prefer hands-on lab problem solving over traditional problem solving.

Sample short questions:
a) List the name of the concepts that you learned using the 3D coordinate system?
b) List the name of the concepts that, in your opinion, should be included in the hands-on activities?
c) Comment on improvement of the system.

C. Survey Procedures

The experimenter (a student researcher) will arrive at the classroom and give a brief overview of the study. After participants read and sign the informed consent, they will be given the paper based survey that requires the student to provide their name. Participants will be asked to rate on the 3D hands-on experiential learning that they experienced over the semester followed by short questions. Participants will be asked to fill out a short demographic survey to indicate their gender, and ethnicity in order to gain general information about the sample. Finally, participants will be debriefed, thanked for their time and dismissed. The entire session will take less than 15 minutes and participants will receive 10 bonus points, or the equivalent to one daily quiz point, for the course. All students who turn in the survey will receive the bonus point. The students will be identified for the bonus point based on the name provided on the survey. The faculty member will leave the room while the survey is administered.

For students not wishing to participate, they will be instructed to leave the survey blank. Afterward all the signed or not signed consent forms will be collected and placed in a manila envelope and will be sealed. The sealed envelope will not be opened until the end of the semester after grades have been turned so that there is no perception of coercion.

D. Comprehension

Final grades from the Fall 2022 and Spring 2023 semester will be compared to previous years to determine if overall student performance in the course is improved. Furthermore, the ELM team will identify specific exam problems and correlate them to the created experiential learning modules. Student performance on these topics will be studied and compared to available data from previous semesters. Lastly, subjective student data on perceived comprehension will be obtained.

To address the growing Latinx student population at Angelo State University, the course equity index [20], [21] will be calculated for final grade results and individual problem data, if possible. The course equity index is a proportionality index that proposes that students of a specific demographic subgroup should perform equally to the entire student population. The index provides a measure of underrepresentation or overrepresentation for a specific grade. It is hoped the experiential learning modules will benefit all students, but will specifically benefit the Latinx student population who, in general, associate with more collectivistic, integrated, or higher context cultural frameworks [17] - [21].

E. Retention

Student retention in the department will be determined pre- and post-implementation, specifically among student cohort groups participating in the experiential learning modules in Statics and Dynamics. In particular, Latinx retention will be examined. All data will be obtained using university databases and the demographic information supplied by the students when enrolling.

Conclusions and Future Work

Overall, the ELM Team is on-schedule to complete two sets of experiential learning modules for Fall 2022, for a total of thirty modules (fifteen for each Statics and Dynamics). To date, one module for each Statics and Dynamics has been developed. The goal for each module is to incorporate the use of experiential learning, including Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE). The modules accomplish these learning modes by:

- Concrete Experience (CE): Students are able to recreate textbook problems using the adaptive 3D Coordinate model.
- Active Experimentation (AE): Students must run an experiment with the problem setup and record real data.
- Abstract Conceptualization (AC): Students must use engineering mechanics principles to calculate theoretical values.
- Reflective Observation (RO): Students answer reflective questions on the real experiment (CE), comment on the accuracy of the recorded data (AE), and predict behavior of new scenarios (AC).

The use of SolidWorks CAD modeling has been key to developing the successful 3D Coordinate prototype unit. The unit performed accurately for both the experiential learning modules reported, with a 2% error observed in the measured forces for the statics module and with a 6% error observed for the measured distances in the dynamics module. It was important to the ELM Team to develop a dimensionally accurate model with user-friendly pieces so that students could be confident in observed or measured mechanics behavior.

Finally, survey data will be collected over the Fall 2022 and Spring 2023 semesters to determine the effect of the experiential learning modules on comprehension and retention, specifically for Latinx students at Angelo State University, a Hispanic Serving Institution. With instructor and student feedback, the learning modules will be improved. Next, a complete literature review of Latinx student performance in introductory engineering mechanics as well as STEM higher education courses will be performed. Course equity and performance on exams and final grades will be monitored to conduct pre- and post-test analysis.

Acknowledgements

The research described herein is part of a project titled “Hand-on Experiential Learning to Improve Comprehension and Retention in Engineering Mechanics” funded by an internal grant through the Faculty Research Enhancement Program at Angelo State University.

Survey data was conducted with the approval of the Angelo State University Institutional Review Board (and if applicable, other relevant IRB committees)- Approval #HAQ-081121. The survey results will be published only in aggregate without any information to personally identify participants. Participation will remain confidential.

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Appendix A: SolidWorks Models and Renderings

The appendix section of this report is intended to share additional information about the project so far. There are additional part drawings and renderings.

Initial Concept Rendering of the 3D Model

There are many possible configurations and setups depending on the learning module, and depending on any future mechanization or measurement instrumentation that may be incorporated into the design. The ELM Team believes the 3D Coordinate unit will be an asset in various engineering courses where physical models of certain mechanics principles can be better learned by students through a hands-on, interactive approach to the subject matter.

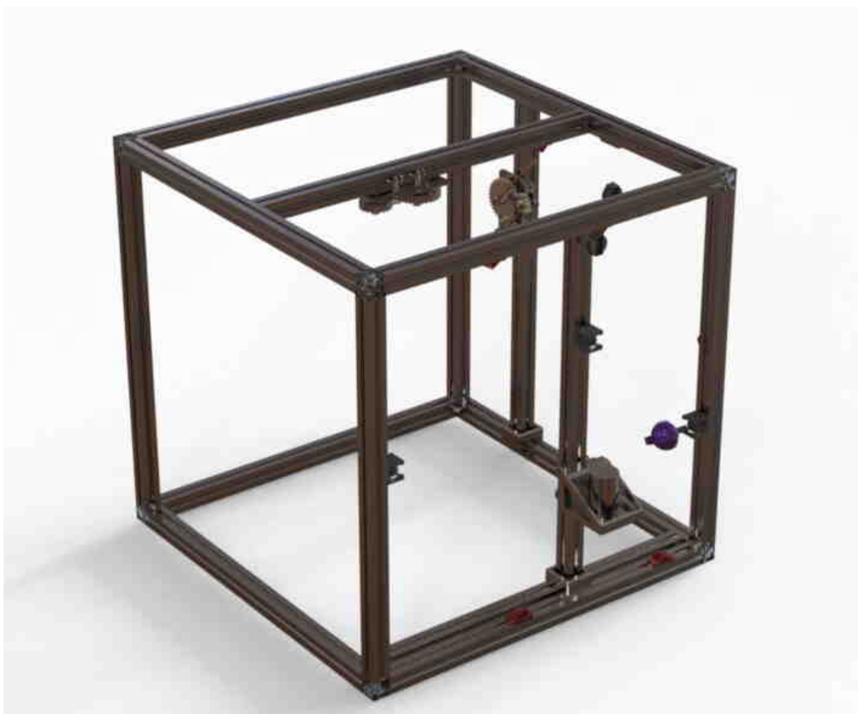


Figure A-1: Initial Concept Rendering

Initial Elevator Concept

The ELM Team is exploring an Elevator Concept for moving various masses in the vertical direction. The modular system allows students flexibility when experimenting with different masses and counterweights. Using a wire-cable-pulley system also provides a very direct and smooth input, which aids in accurate measurement taking.

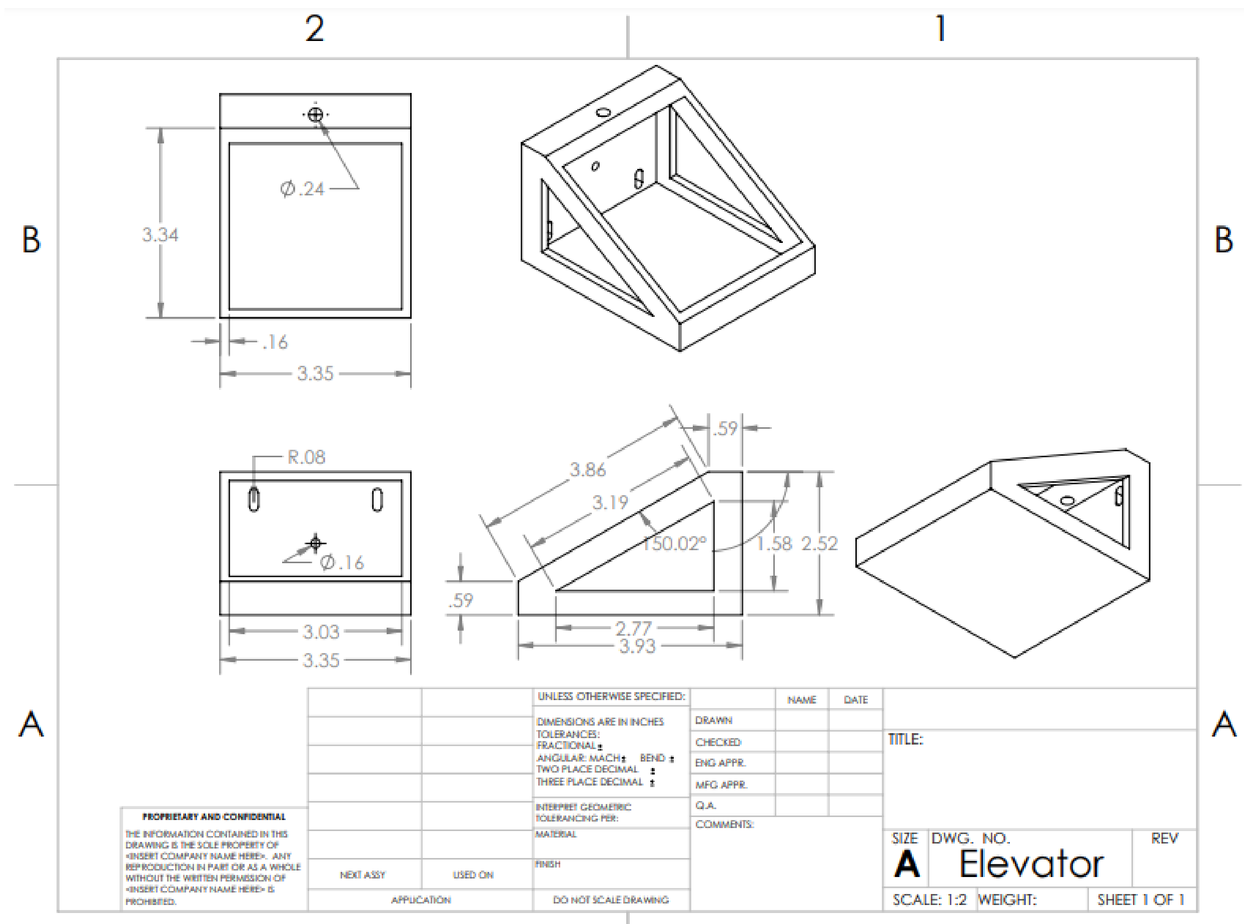


Figure A-2: CAD Drawing of Elevator Concept

Aluminum Extrusion Basic Dimensions (inches)

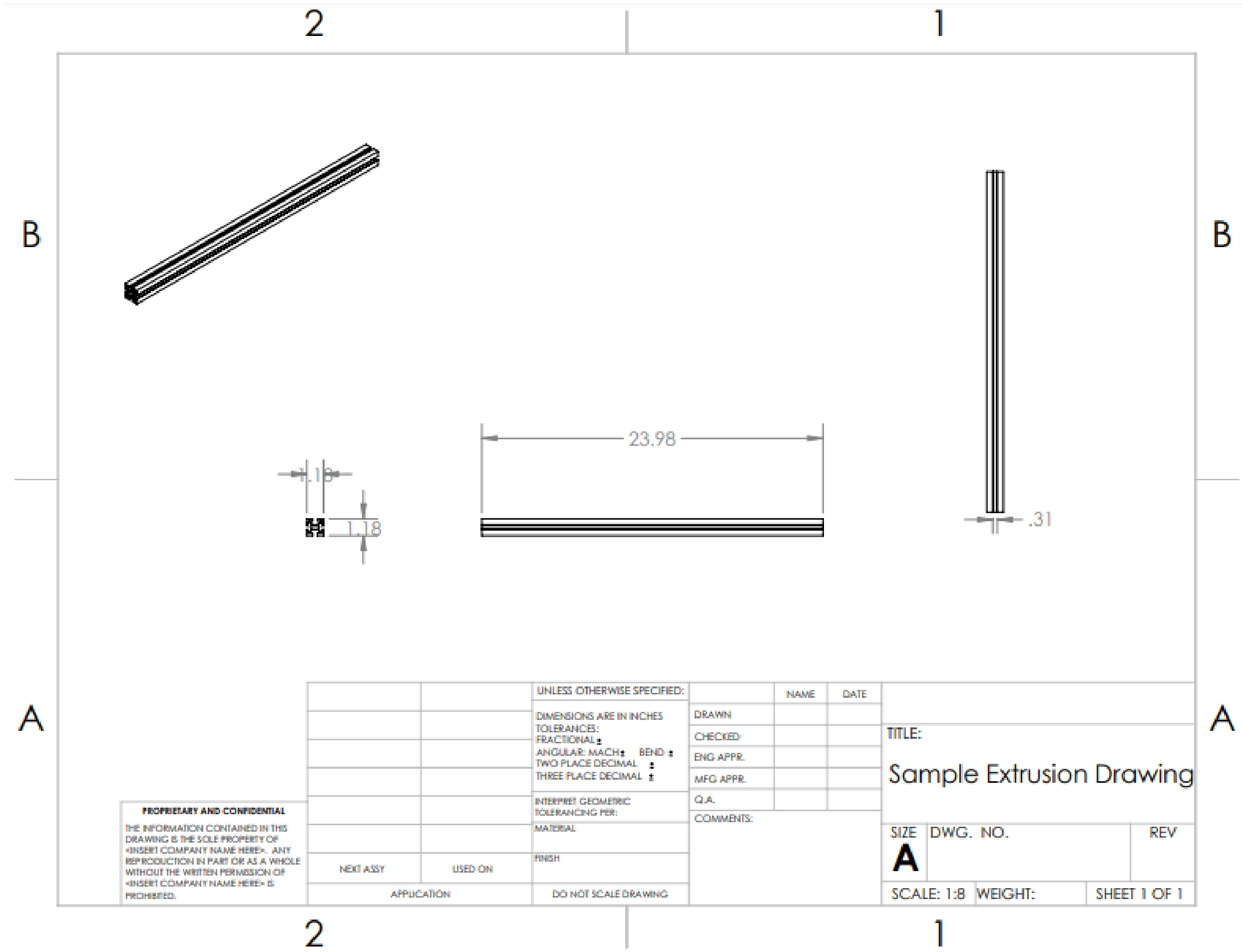


Figure A-3: CAD Drawing of Aluminum Extrusion

Idealized Boundary Condition: Ball and Socket

The drawing depicts a ball and socket adapter concept for various fixtures requiring dynamic movement. The adapter will be very useful as a part of the modular system for a number of different model configurations as it allows a great degree of freedom in movement. It will be able to attach at any point in the model and not take up too much space. It could easily be used in the modeling of statics problems that require anchor points with adjustable angles.

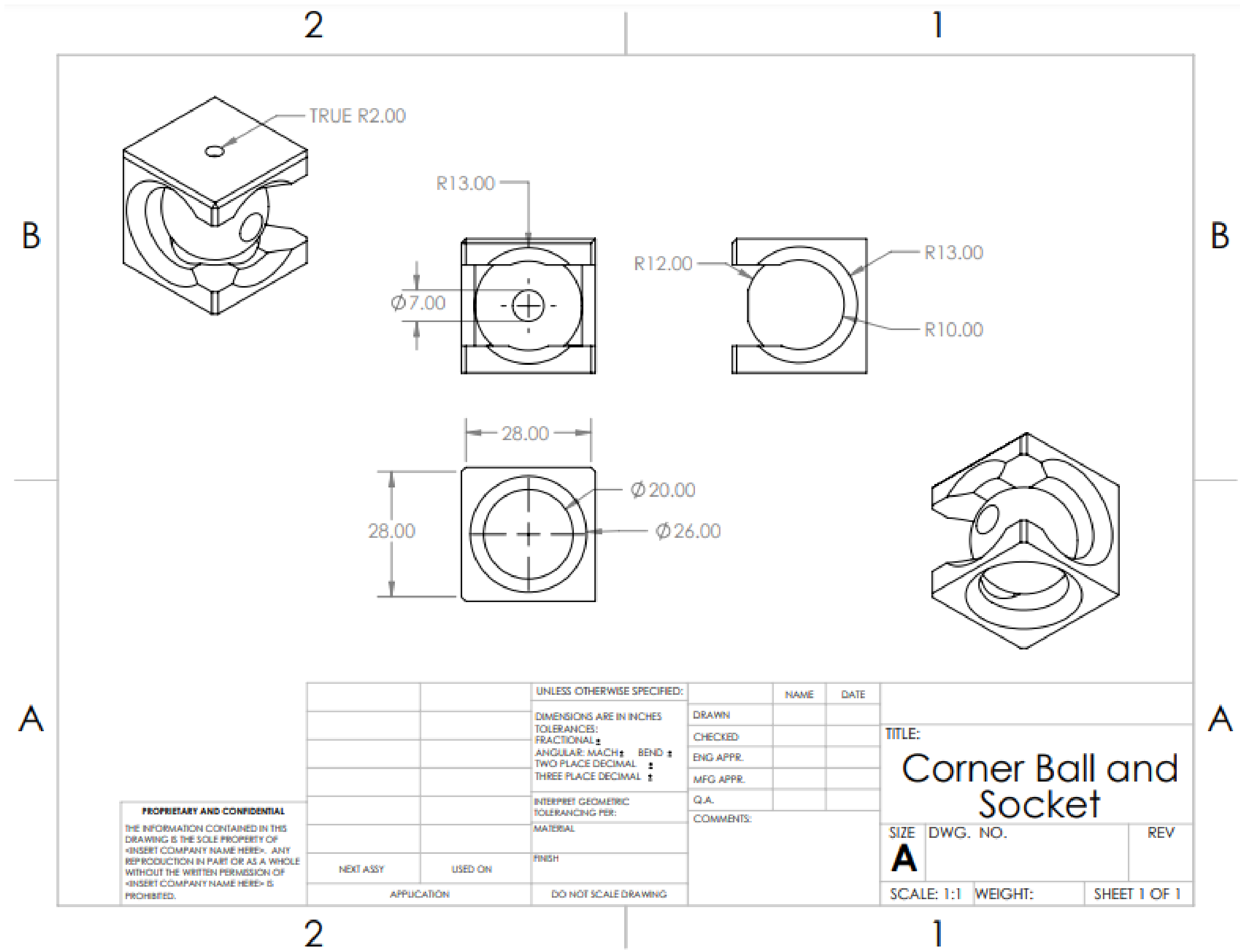


Figure A-4: CAD Drawing of Ball and Socket

Appendix B: Detailed Survey Results

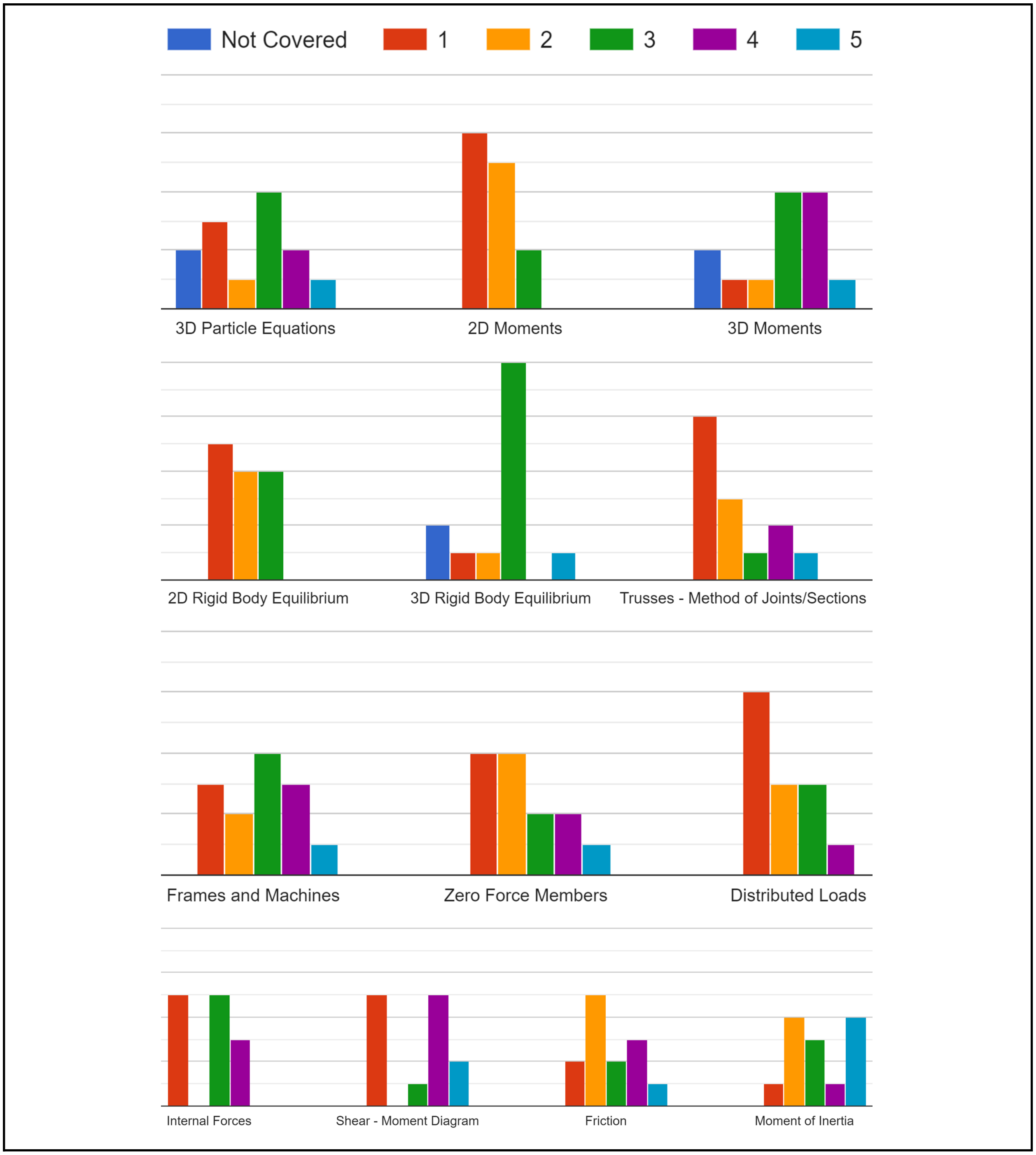


Figure B-1: Students (13 participants) - Statics Survey Data

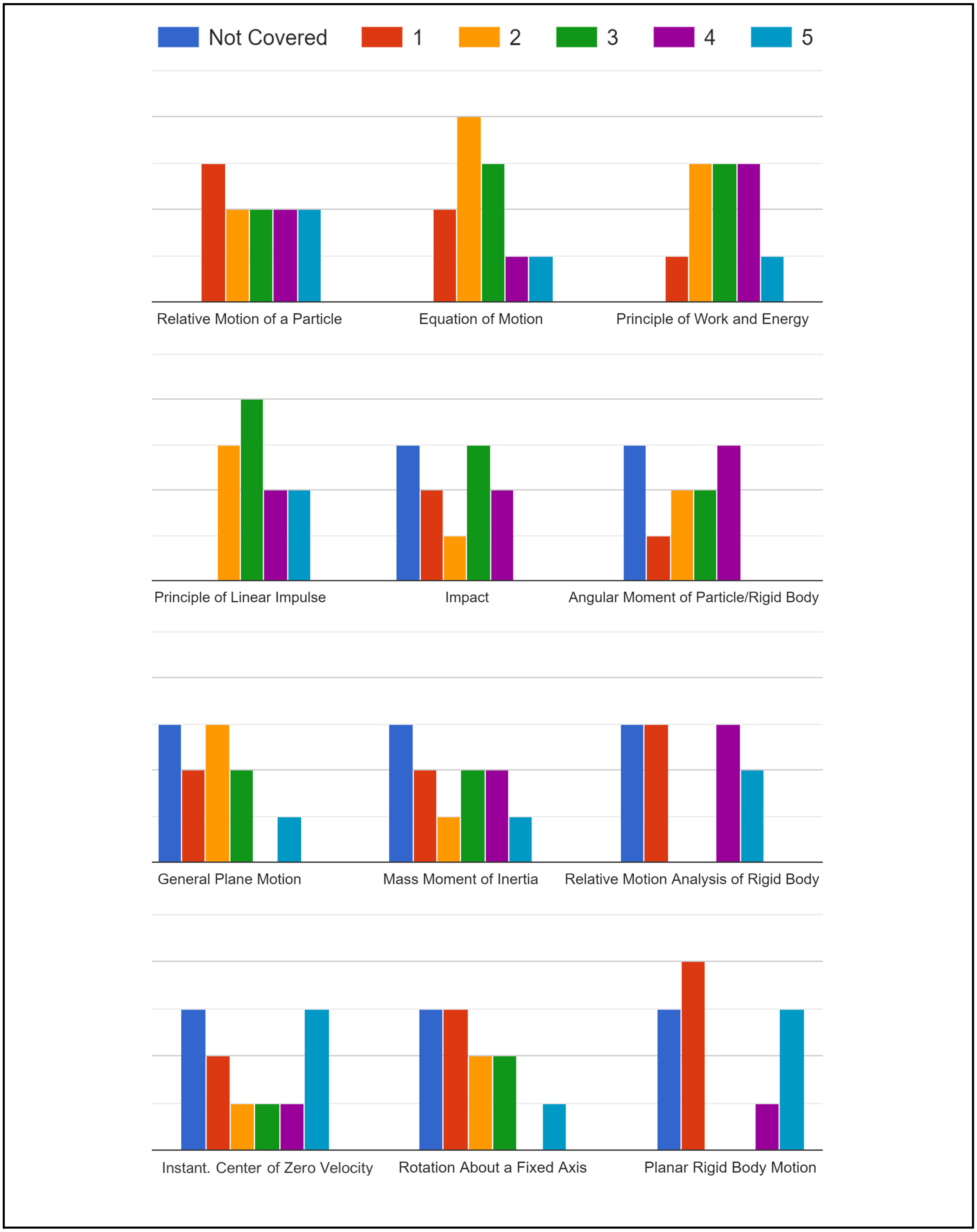


Figure B-2: Students (11 participants) - Dynamics Survey Data

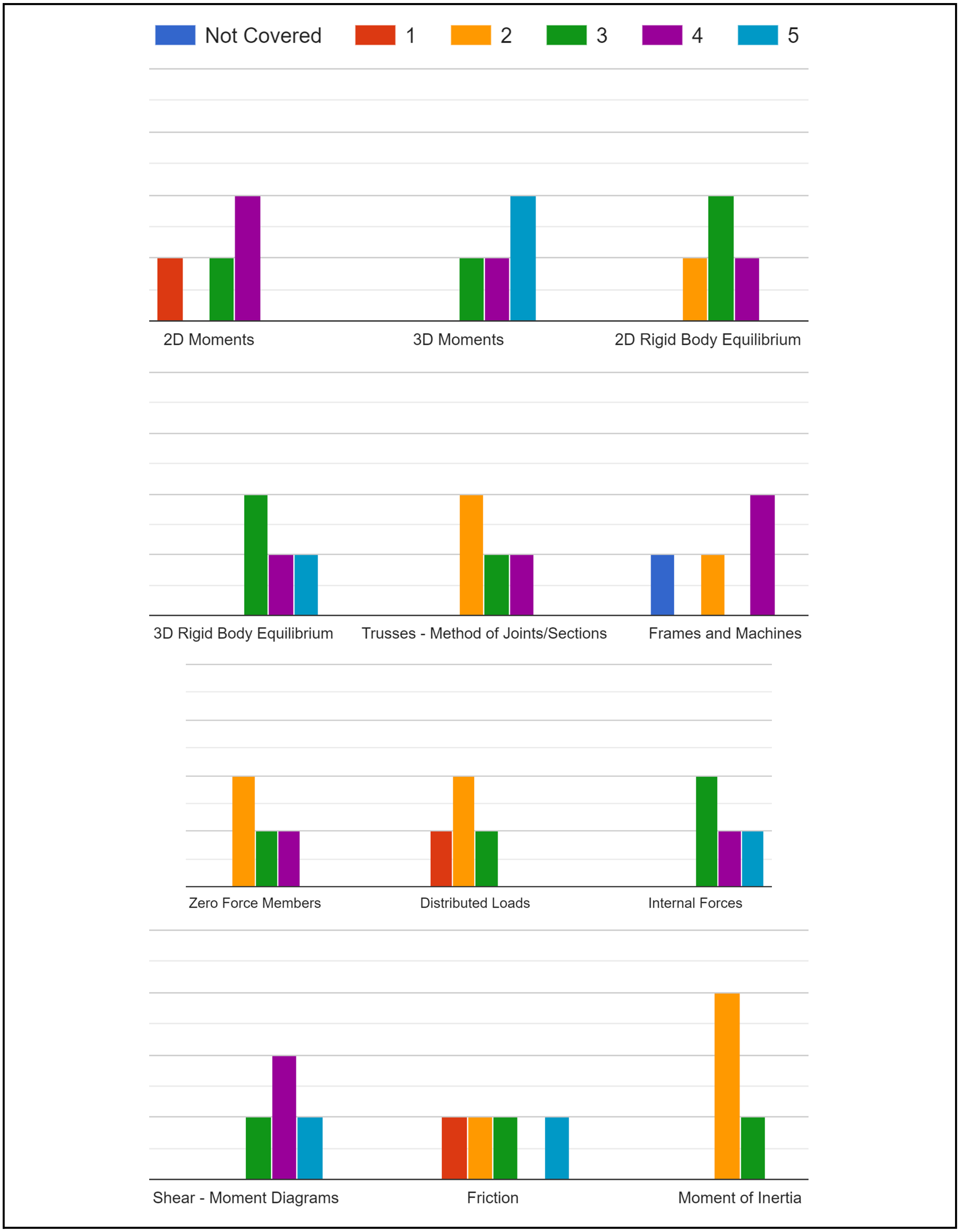


Figure B-3: Instructors (4 participants) - Statics Survey Data

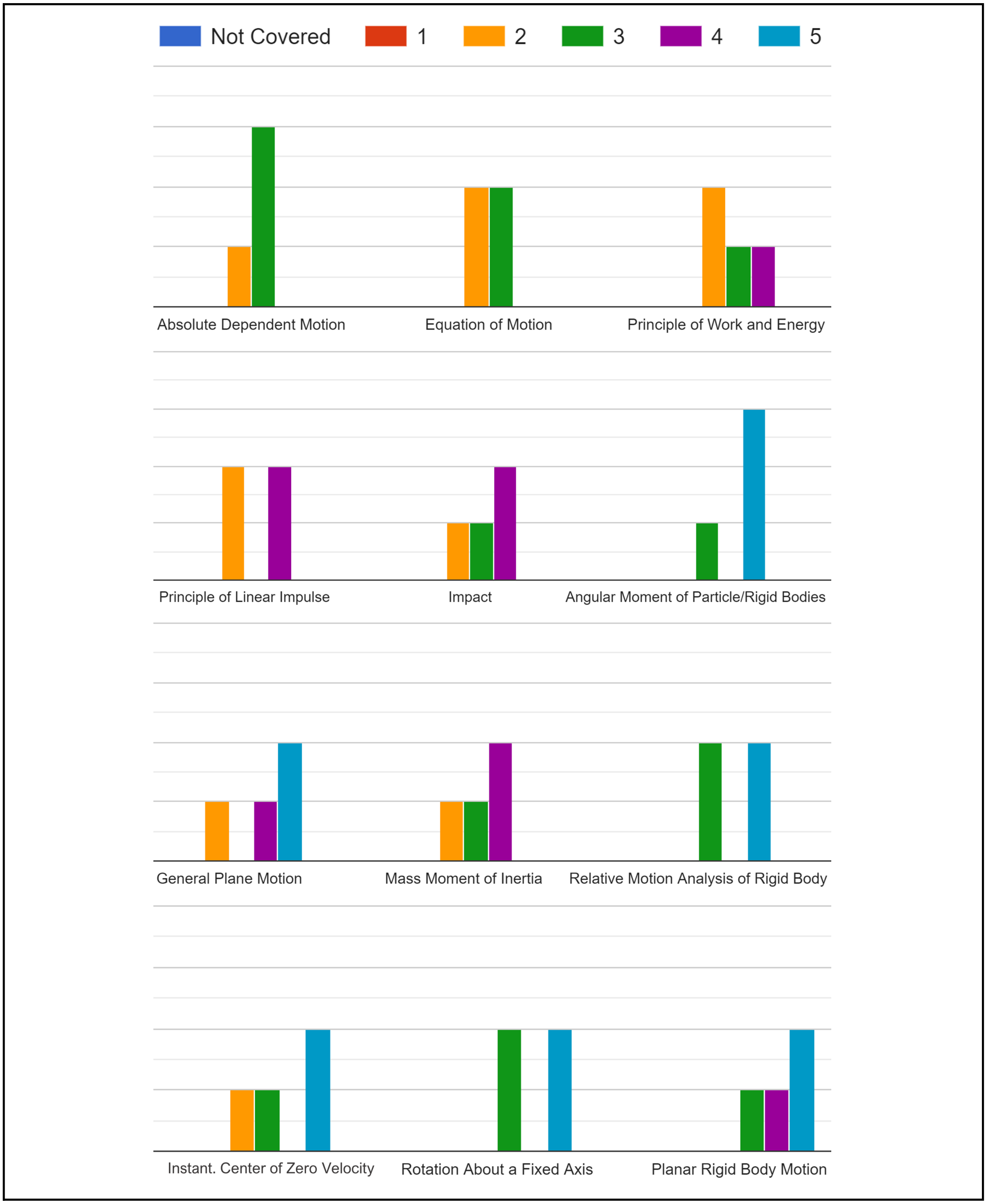


Figure B-4: Instructors (4 participants) - Dynamics Survey Data

Appendix C: Statics Experiential Learning Module

A typical example from a textbook is seen in Figure C-1. The module will also allow students to understand the expectations of the use of the 3D coordinate model test unit for the remainder of the semester.

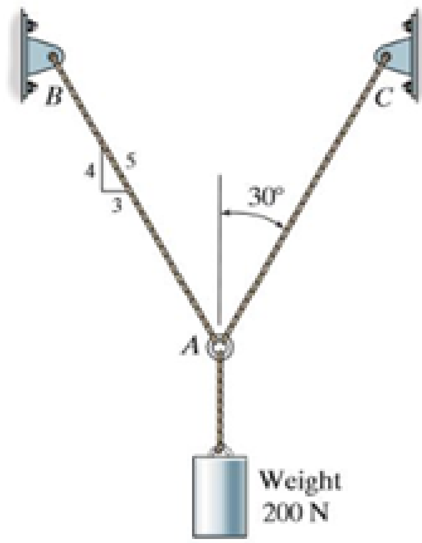


Figure C-1: Typical 2D Particle Equilibrium Textbook Problem [26]

Using spring force gauges in conjunction with cables and a hanging mass, the tension in each spring gauge can be experimentally observed. Likewise, the theoretical force in each cable can be solved using sum of force equilibrium equations. Lastly, if the length of the cable is changed, students can use the law of cosines and sines to determine the new problem geometry, to allow for additional comparison of theoretical forces to observed forces.

The following is an outline and an initial development of this problem for students to complete in a laboratory class, keeping assembly and completion time in mind.

Laboratory 1: Experiential Learning Module for Principle of 2D Static Equilibrium

Task 1: Observe a two-cable system in static equilibrium.
Learning Objective: Solve the forces in each cable using equilibrium and compare the results to measured values using the 3D coordinate model.

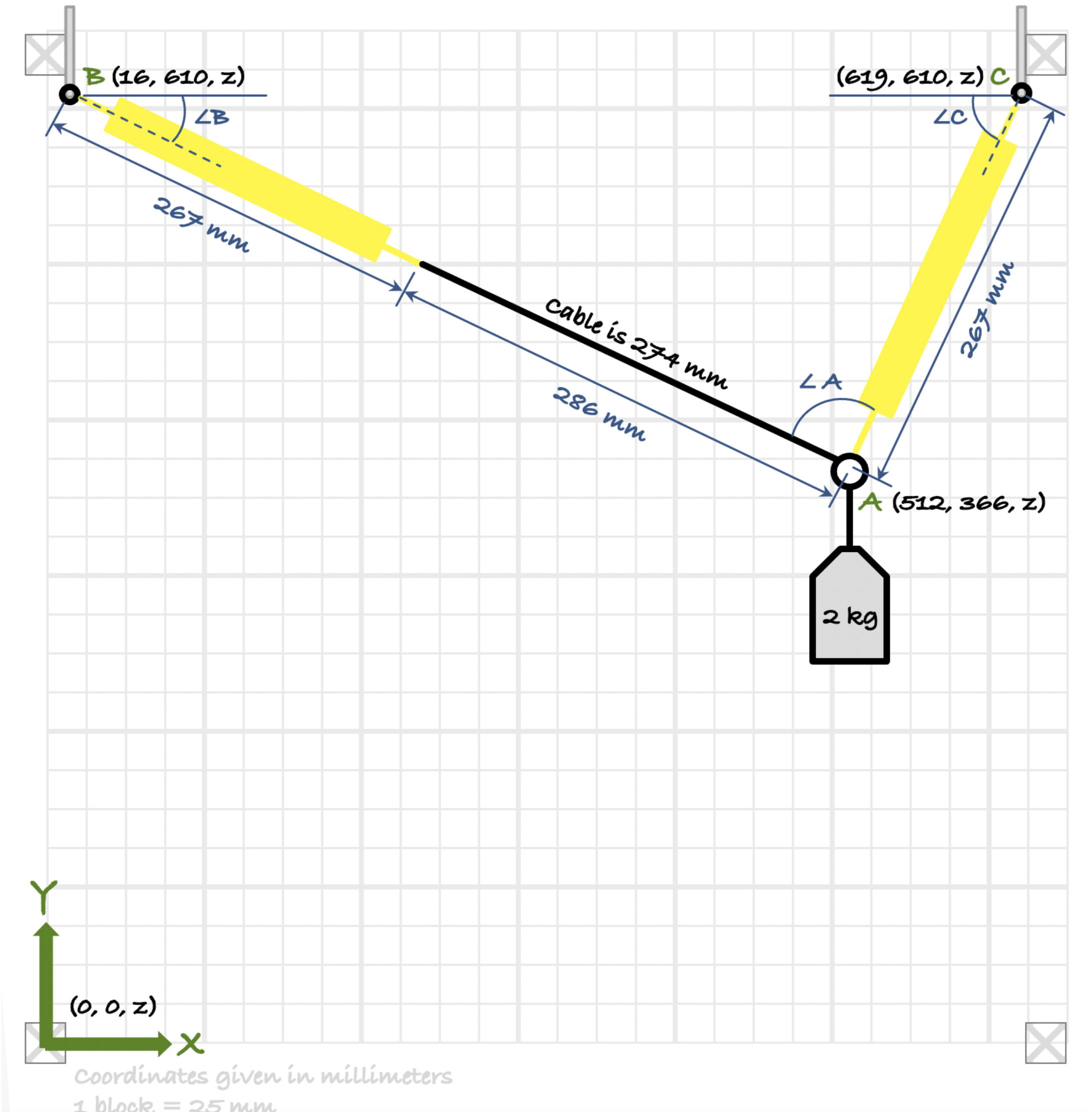


Figure 1-1: Problem Layout

A. Using the adaptive 3D coordinate model, assemble the two force gauges, the provided 274 mm cable, and the 25 mm diameter keyring as shown in Figure 1-1.
   Note: For accurate results in this 2D problem, make sure the force gauges and key ring are at the same z coordinate value by locking the sliding mechanisms in place.
B. Zero each force gauge using the white plastic nut located at one end.
C. Using the weights given, carefully hang 2 kg of mass on the keyring.
D. Record the tension in each force gauge to the nearest tenth below, while avoiding contact with the setup to prevent fluctuations in springs.
   - Experimental T_{AB}: Sample answer: 8.0 kN
   - Experimental T_{AC}: Sample answer: 17.5 kN

E. Use the law of cosines to calculate the interior angles at A, B, and C.
- $\angle$A: Sample answer: 87.38°
- $\angle$B: Sample answer: 26.25°
- $\angle$C: Sample answer: 66.37°

F. Utilize static equilibrium equations to solve for the tensions in cables AB and AC.
- Theoretical T_{AB}: Sample answer: 7.87 kN
- Theoretical T_{AC}: Sample answer: 17.62 kN

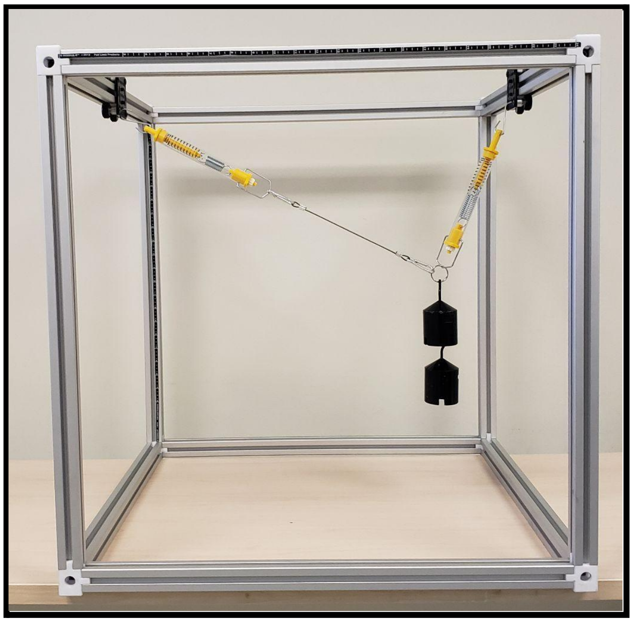


Figure 1-2: Front View- Fully Assembled for Analysis

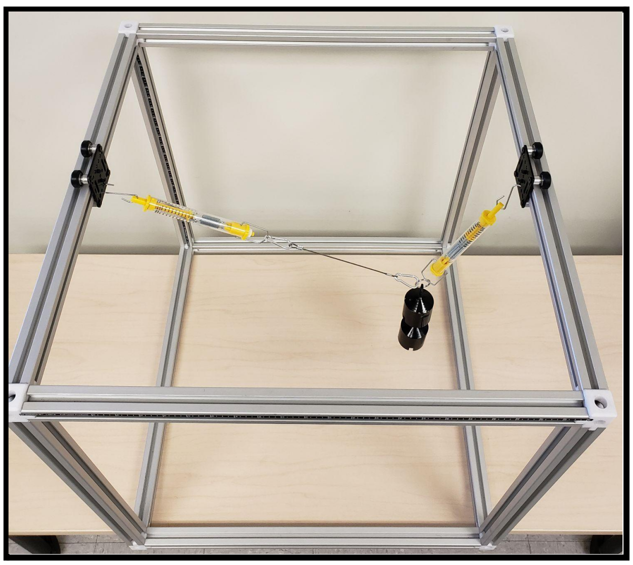


Figure 1-3: Top View- Fully Assembled for Analysis

Task 2: Group Discussion Regarding the Effects of Angles on Forces
Learning Objective: Determine the effect that angles have on resultant forces.

A. As a group, predict if the forces in the cables/gauges will increase or decrease if the distance between points B and C is increased.
   - Prediction: ____

B. Unlock the force gauge at point B and slide it in the z-direction to increase the distance between B and C. Record the new forces in each gauge below.
   - Experimental T_{AB}: ____________
   - Experimental T_{AC}: ____________

C. As a group, discuss these results. Did it match your prediction? Write the reason(s) that you believe are causing these forces to change.
   - Sample answer: As ∠B and ∠C decrease, the ratio of the y-component to the tension in both cables becomes smaller. Therefore, an increase in tension in both cables is required for equilibrium with the same mass in the y-direction.

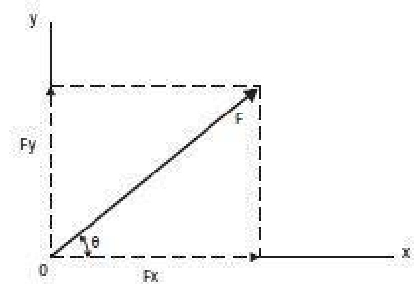


Figure 1-4: Resultant Force Components

Formulas:

Sum of Forces:

$\Sigma F_x = 0$

$\Sigma F_y = 0$

Law of Cosines:

$C^2 = A^2 + B^2 - 2ABcos(\theta)$

Percent Error:

$$\frac{Tension_{theo.} - Tension_{exp.}}{Tension_{theo.}} \times 100 = \%\ Error$$

Questions:

A. How would the tensions in the force gauges change if mass was removed/added? (i.e. if only 1 kg was applied or if 3 kg was applied) Is there a relationship to the calculations performed in the lab?
____
____
____
____

B. Using the percent error formula, calculate your team's error using the values from Task 1, Steps D and F.
   a. T_{AB}: Sample answer: +1.65%
   b. T_{AC}: Sample answer: - 0.68%

C. List any other formulas your team may have used to analyze this laboratory below.

D. How can Microsoft Excel/Python/Matlab assist your team in the analysis of increasingly complex problems such as this one?
____
____
____

Lab 2 Pre-Assignment:

In Lab 2, your teams will be asked to perform the same experiment several times, but with different supplied cable lengths along segment AB.

Using Lab 1 as a guide, develop a spreadsheet that performs the following:

- Determines Angles A, B, and C depending on the cable length given.
- Calculates the tensions in both segments AB and BC.
- Presents a table to compare observed forces with theoretical calculations.
- Calculates experimental percent error.

Appendix D: Dynamics Experiential Learning Module

Laboratory 1: Experiential Learning Module for the Principle of Work and Energy

Task 1: Observe the motion of a pulley-block system
Learning Objective: To observe the effect of gravitational acceleration.

A. Take the adaptive 3D coordinate model and assemble the pulley and blocks as shown in the Figure 1-1 below using the supplied cord. The pulleys are positioned in a plane at the middle of each arm.
B. Take the measurement of X. Select the blocks A, B and C of the same masses.
C. Hold block-A approximately at horizontal position at the middle of the cord and release. Observe the motion of the three blocks.
D. Using your cell phone or a camera to record a slow-motion clip of the blocks (make sure the printed ruler attached to the arm of the 3D system is visible). Repeat if needed.

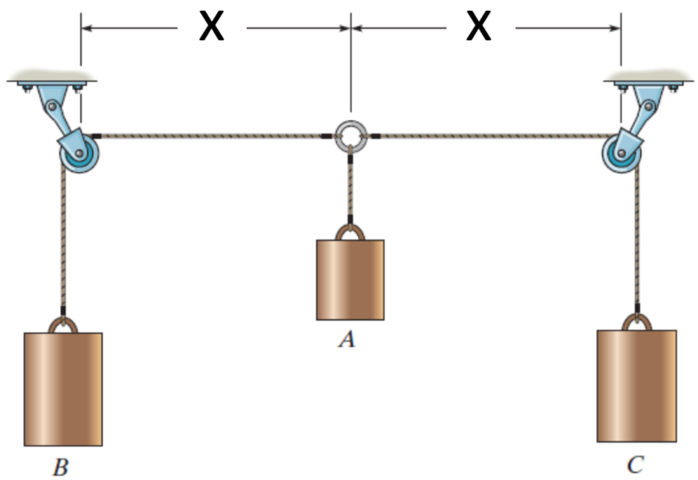


Figure 1-1: Pulley-block Problem Setup [adapted from 27]

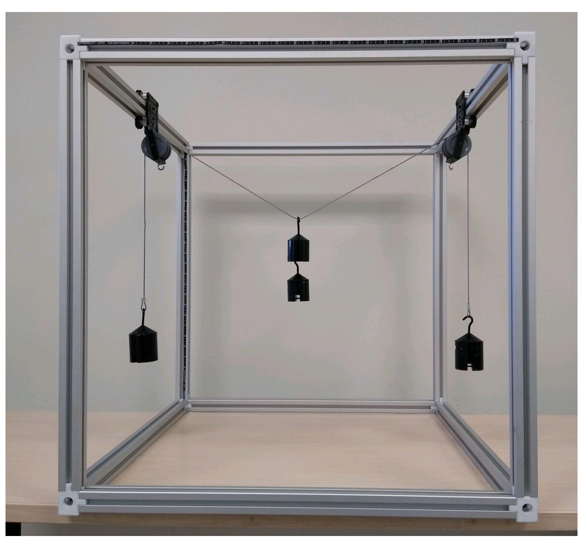


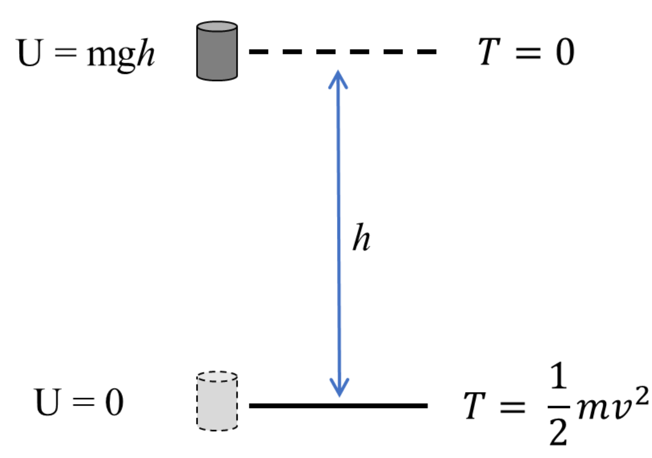
Figure 1-2: Adaptive 3D Coordinate Setup for learning Module

Task 2: Reflective observation of pulley-block system motion
Learning Objective: To relate potential and kinetic energy with real world scenarios.

A. State if block A falls beyond the vertical position when it comes to a stop?
   a. Sample answer: YES
B. Why do you think the block fell more than the position it came to stop?
   b. Sample answer: A release of block A creates an unbalanced force due to gravitational acceleration. Potential energy converts to kinetic energy; three masses bounce up and down and momentarily come to a stop.
C. What is the measured distance (X) from pulley to block A?
   c. Sample answer: For the current set up (Figure 1-2), X = 1 ft.
D. What is the maximum distance (Y) traveled by block A?
   d. Sample answer: For the current set up (Figure 1-2), Y = 1. 25 ft. (Estimated from slow motion video)
E. Is the final distance fall by block A after coming to a stop longer or shorter than the maximum distance (Y)?
   e. Sample answer: The maximum distance (Y) is higher than the final distance.

Task 3: (Abstract Conceptualization) and Validation
Learning Objective: Analyze the system mathematically, either as a predictive or verification method in order to validate the theory being taught in the module.

A. For a given mass (m) released from a known height (h); What is the potential energy at the moment of release? and What is the potential energy at the base (h=0)?
B. For a given mass (m) released from a known height (h); What is the kinetic energy at the moment of release? and What is the kinetic energy at the base (h=0)?
C. The potential energy converts to kinetic energy, thus the work done (change in potential energy) is equal to the change in kinetic energy (column 2).

Column 1	Column 2	Rectangular Coordinate
$U = mgh$ $T = \frac{1}{2}mv^2$	$T_1 + \Sigma U_{1-2} = T_2$	

D. Using the Principle of Energy equation and trigonometry, determine the (figure 2 set up, X = 1ft) maximum distance (Y) traveled by the block A?
   a. Sample answer: Theoretical maximum traveled distance (Y) = 1.33 ft.
E. Compare your answer from Task 1
   b. Sample answer: Error: 6%

Task 4: Challenge Problem: Perform additional experiment using the module in a different configuration.
Learning Objective: To recognize and solve problems using Work & Energy balance.

Reposition the pulleys at each corner (diagonal position) such that the distance X is longer than the 1st test performed in Task 1 (see Figure 1-3), and repeat the test.

Compare your calculated distance in Task 4 with Task 1. Are the distances traveled the same? If not, why? Is it because of a change in the distance x? Explain.

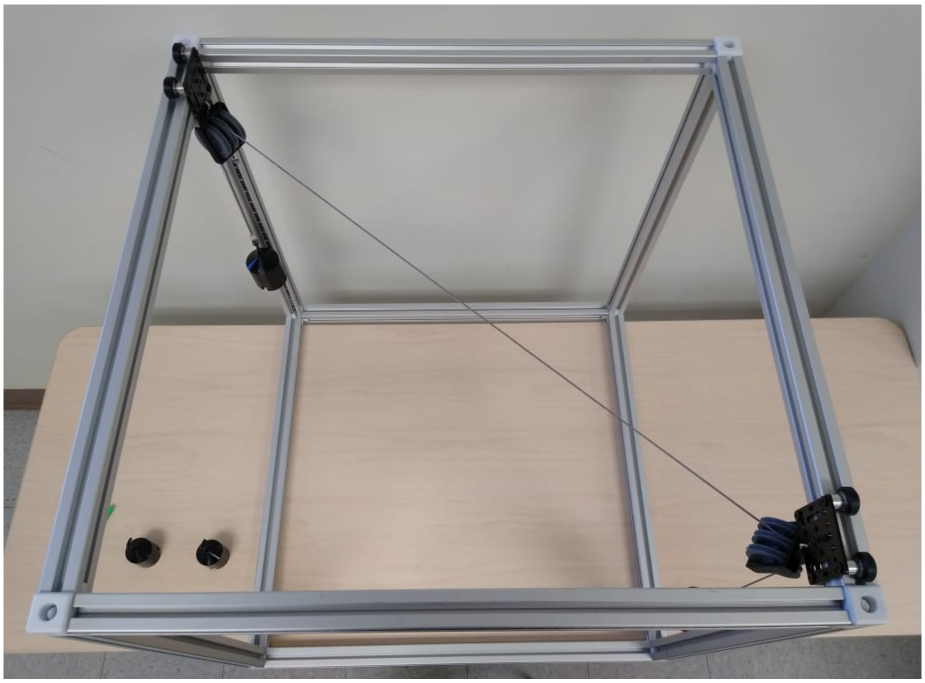
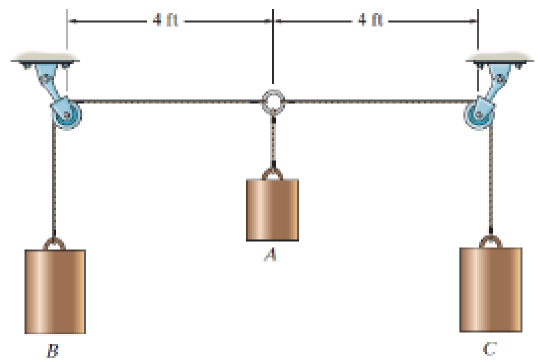


Figure 1-3: 2nd setup repositioning the pulleys at the corners with longer X length

Detailed Solution for Dynamics Module

14–18.

When the 12-lb block A is released from rest it lifts the two 15-lb weights B and C. Determine the maximum distance A will fall before its motion is momentarily stopped. Neglect the weight of the cord and the size of the pulleys.



SOLUTION

Consider the entire system:

$$l = \sqrt{y^2 + 4^2}$$

$$T_1 + \Sigma U_{1-2} = T_2$$

$$(0 + 0 + 0) + 12y - 2(15)\left(\sqrt{y^2 + 4^2} - 4\right) = (0 + 0 + 0)$$

$$0.4y = \sqrt{y^2 + 16} - 4$$

$$(0.4y + 4)^2 = y^2 + 16$$

$$-0.84y^2 + 3.20y + 16 = 16$$

$$-0.84y + 3.20 = 0$$

$$y = 3.81 \text{ ft} \qquad \textbf{Ans.}$$

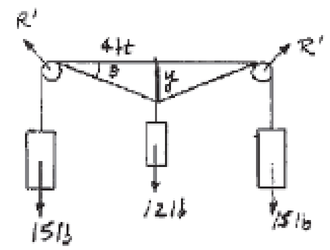


Figure D-1: Dynamics Module Textbook Solution [27]