Hands-on Experiential Learning Modules for Engineering Mechanics (Work-in-progress)

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Abstract

Experiential learning includes concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) modules to form a complete learning cycle. It promotes active learning and can significantly improve comprehension of engineering mechanics problems. This paper discusses our implementation of experiential learning modules in Statics and Dynamics. The learning modules are used in the laboratory sessions where a faculty and a supplemental student instructor administer the session.

This is the second in a series of work-in-progress reports on a program to develop and implement hands-on experiential learning modules in statics and dynamics classes at Angelo State University. The previous report discussed work to identify topics for experiential learning modules and the creation of learning modules for statics and dynamics. This report discusses the deployment of new modules and data collection from student surveys, and faculty feedback. This study reports the survey results over several semesters and feedback from multiple instructors' teaching statics and dynamics. The student feedback on the experiential modules suggests improved comprehension. The students indicated that they learned a concept better when observing a physical model of the principle.

Most students find the hands-on learning modules interesting, fun, and engaging. In addition, at least one new experiential learning module for Statics and one for dynamics will be presented. Finally, the scope of improvement based on a student survey, and faculty experience will be provided.

Introduction

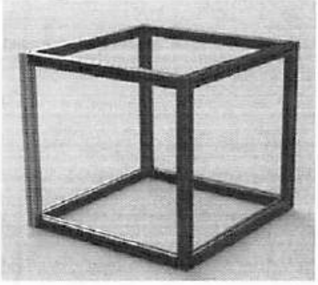
Motivation

Engineering mechanics courses (Statics and Dynamics) are a prerequisite for many upper-level engineering courses in most universities; however, a high drop-out rate is widely reported [1-2]. Research suggests that using hands-on equipment for engineering mechanics courses facilitates active learning and significantly improves comprehension of engineering mechanics problems [3-17].

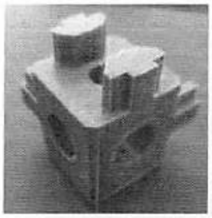
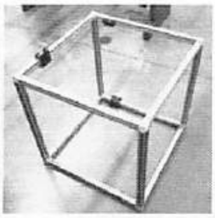
Over the years, several learning approaches have been proposed using hands-on equipment such as the "engage (see-feel-practice-apply) strategy", "experimental problem solving", "guided discovery", and "inquiry-based learning" [7-11]. Recently, an integrated "experiential learning" that includes all modes of learning is reported to be effective for knowledge acquisition [12-14]. Experiential learning includes four processes: Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experiments (AE).

Table 1: Steps performed to develop the 3D coordinate model

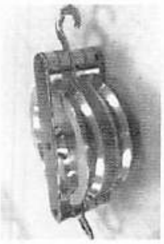
Member selection:
Aluminum extrusions were selected due to their lightweight, corrosion resistance, and ease of machining compared to steel. A T-shaped channel allows mounting various fixtures on the extrusion facilitating various statics and dynamics problems set up in 3D space. SolidWorks CAD models were used to visualize the system and to verify geometric constraints.



Prototype:
A corner joint was modeled and 3D printed to mate three extrusions at the corner of the 3D model. Extrusions were cut into 2 ft long pieces and assembled using the corner joints and screws.

Off-the-shelf elements and custom-made supports:
Add-on elements such as carabiners, key rings, force meter spring scale, weights, rolling flanges, and pulleys are purchased off-the-shelf for ease of replication. However, some supports are 3D printed to match special needs such as ball and socket swivel joints.




Angelo State University survey and topics selection:
Researchers performed a survey for Statics and Dynamics among university students and faculty to identify critical topics for hands-on experiential learning. Seven topics for each Statics and Dynamics were selected based on the survey.

3D Coordinate Model

The Experiential Learning in Mechanics (ELM) team at Angelo State university developed an adaptive 3D coordinate model that facilitates the re-creation of various textbook problems. The steps to create the physical 3D model are summarized in Table 1. A detailed description of each step is reported in previous work [17]. Full learning modules for the "Principle of 2D Statics Equilibrium" and "Principle of Work and Energy in Dynamics" were also reported previously [17]. In this paper, two new modules "Principle of 3D Statics Equilibrium" for Statics and "Dependent and Relative motion" for Dynamics is reported.

New Learning Modules

Learning modules are designed to include the four processes of experiential learning and to be completed in a 50-minute laboratory period. The problems are developed on a selected topic to mirror typical textbook problems so students can begin to translate 2D drawings into real, physical 3D engineering applications.

Statics Learning Module
For an introductory problem and proof of concept, the use of a classic, planar, two-cable problem was selected to be the first Statics learning module created [17]. To build familiarity with the setup, as well as increase student confidence in the application, a three-cable problem was developed to demonstrate 3D equilibrium principles. The complete module is available in Appendix A.

The following summary identifies how the 3D equilibrium module addresses the aspects of experiential learning:

- Concrete Experience: In Task 1, students are asked to assemble a 3D cable problem supporting a hanging weight and to observe the force measured by each spring force gauge.
- Reflective Observation: In Task 2, students must perform unit vector analysis on the system to determine the theoretical forces in each cable. Once complete, students must compare the measured forces from Task 1 to the theoretical values and calculate the percent error. This process is mapped out in Task 2 to help facilitate a step-by-step solution.
  - It is envisioned that Task 2 could be a homework problem or assignment to be solved before the lab session as the solution could take beginner students time to complete.
  - Alternatively, a spreadsheet was developed to perform the equilibrium calculations and can be shared with the students to complete the theoretical calculations.
- Lastly, if the instructor is looking to include more engineering technology and software in the class, the instructor could require the students to create their spreadsheets capable of completing the calculations. Caution: Depending on your degree program, the students may or may not have had matrix mathematics, which was deemed the easiest way to complete the necessary 3 equation system in the spreadsheet calculations.
- Abstract Conceptualization: Task 3 requires the students to predict how the forces would be affected if more/less mass is added or if one cable length is changed.
  - More/less mass: While most students will assume that more mass will increase the forces in the cables, the question makes them consider the linearity of the system. Since spring gages are utilized as the cables, there is some non-linearity as deflections at the mass can cause significant changes in geometry.
  - Cable length: Students should predict how cable tensions will change due to the shortening of a cable.

- Active Experimentation: In Task 3, students may add/remove mass to see if their predictions are correct. In Task 4, students switch the length of one of the cables and record the new geometry and new measured forces. Students can visually confirm their abstract conceptualization of the problem, and with the updated geometry and spreadsheet, should quickly see once again that the equilibrium equations do indeed predict the measured forces.

Dynamics Learning Module

The dynamics learning modules are generated based on selected textbook problems. Worksheets are developed that include four tasks that will facilitate experiential learning and hands-on problem solving (a newly developed module shown in Appendix B):

- *Concrete Experience:* In Task 1 the students are asked to assemble multiple pulley-block systems similar to the textbook problem and observe the relative and dependent motion of the blocks.
- *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:* In Task 3, the students are required to relate their observations in Task 2 to derive the equations for dependent and relative motion analysis.
- *Active Experimentation:* At the end of Task 3, students are given a similar challenge problem. In the problem, students will verify theoretical results with actual measured values.

Ongoing Assessment

Student Feedback

The full list of the questions is given below. In addition, the student was asked about their ethnicity and gender.

Table 2: Survey results of students' evaluation on Statics and Dynamics hands-on learning over Spring and Fall 2022 semesters [Total % = Strongly agree + Agree]

Survey Questions	Statics (31 responses)	Dynamics (21 responses)
1. I enjoyed the course more because of the hands-on learning module(s) during the lab session.	85% (33%+52%)	61% (47%+14%)
2. The hands-on learning module helped me better comprehend the principles it employed.	84% (39%+45%)	58% (29%+29%))
3. I learn a concept principle better when I can observe a physical model of the principle.	84% (23%+61%)	81% (33%+48%)

4. I would prefer the hands-on problem-solving module over textbook problem-solving during the lab session.	**90% (30%+60%)**	**67% (29%+38%)**
5. The hands-on learning module was interesting, fun, and engaging for me.	**100% (33%+67%)**	**71% (42%+29%)**
6. I am confident I could solve similar problems after having completed the lab.	**87% (39%+48%)**	**43% (29%+14%)**
7. I learn better with active tasks than in the normal lecture setting.	**86% (38%+48%)**	**61% (42%+19%)**

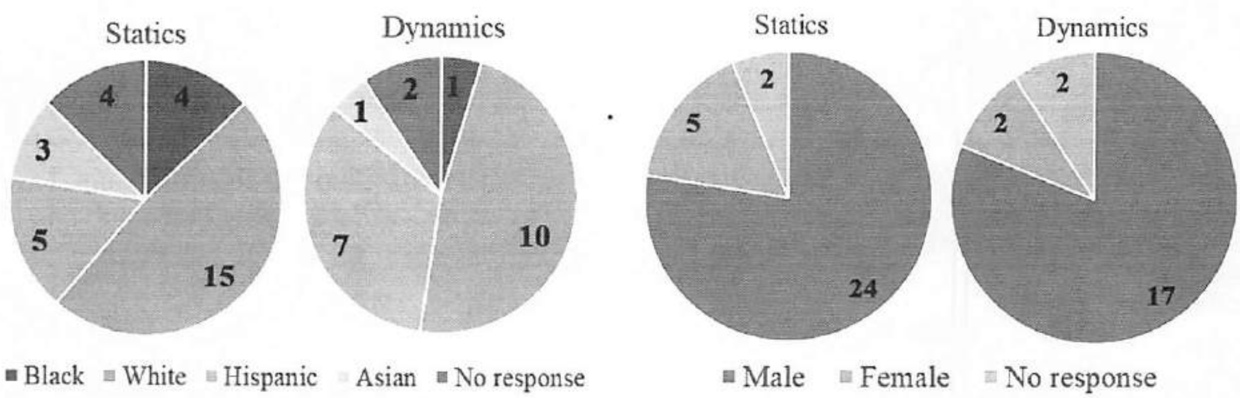


Figure 1: Gender and racial demographic of the population

Table 3: Summary of students' comments for improvement

Statics:

1. Explain the procedure with an example before.
2. A mixture of hands-on learning and textbook questions would help solidify the material.
3. Have longer labs, the 50 min has a bit short for some of the modules.
4. I would love more hands-on labs.

Dynamics:

1. Learning modules should be uploaded earlier.
2. Go over the module before the tasks.
3. More clarity in the instruction and list all necessary equations.
4. Add more information on the worksheet and more help from the professor.
5. The module setup is a little complicated, so if it was simplified it would be better.
6. More equipment and better-measuring devices.

Student Feedback: Statics (Spring 2022, Fall 2022)
Table 2 presents survey results of students' evaluation of the hands-on learning module. Over 80% of students from Static classes provided positive feedback and answered that hands-on learning modules were helpful for concept learning. During the hands-on labs, students were actively engaged with the modules and worked together as a team to solve the given problems. For the 3D Equilibrium Lab, some student groups created their own 3D static problems and solved them, then subsequently tried to test the problems using the hands-on module.

Regarding the demographics of the Statics class, about half the students are white students while the other half of the students are Hispanic, black, and Asian students, including students with no response (Figure 1). The majority of the students are male (over 75%) according to Figure 1, which currently correlates to the enrollment in engineering at Angelo State University. A concurrent goal of the research is to determine if the Experiential Learning Modules developed disproportionately benefit historically minoritized populations, particularly the Latinx students served by Angelo State University as a Hispanic Serving Institution (HSI).

Lastly, Table 3 includes a summary of students' comments for improvement, most notably that students want to have more hands-on labs and longer lab sessions. In addition, students requested more instruction before the lab and a firmer connection between hands-on activity and textbook questions. One major goal for the researchers is to strengthen the link between classes and labs, especially as the researchers leading the project are not currently the course instructors. However, this is a productive situation, as it has highlighted difficulties with the modules and led to improvements, which will hopefully facilitate the adoption of the modules by instructors at other institutions.

Student feedback Dynamics (Spring and Fall 2022)
The gender and racial demographics of the population are illustrated in Figure 1. A total of 21 students over the Spring and Fall of 2022 participated in the survey, where 47% are identified as White and 33% are identified as Hispanic, the remaining 20% include Asian, Black, and those who do not want to disclose their racial identity. About 81% of the students are identified as male whereas the female and those who do not want to disclose consist of 9.5% each.

The survey results and student comments are listed in Table 2 and Table 3 respectively. Based on the student survey, more than 80% of students agree or strongly that they learn a concept better when they can observe a physical model. Though 71% agree that the hands-on problem-solving was interesting, however, only 43% expressed confidence that they will be able to solve similar problems. Some reason behind in lack of confidence is reflected in their comments.

In comments for improvement, the students suggested some important modifications if adopted would improve their experience. The modules should be uploaded at least a week earlier, and it would be easier for the students to follow the worksheet if the instructor explain the tasks in a short briefing. It seems the worksheets need to be revised for clarification, there are two ways to do this: (a) further breakdown the task with an additional description which may be limited due to 50 min time restriction. A longer lab duration may be helpful to go through it step-by-step. (b) to reduce sub-tasks such as the derivation of the formulas since that may be covered in the classroom and break down the remaining tasks into sub-steps. Further, improvement suggestions are reflected fro instructors' feedback.

Faculty Feedbacks

Faculty feedback 1:

"Incorporating the project into an engineering statics course was relatively simple. This particular statics course had a problem-solving laboratory time already in the course schedule. The implementation was a simple process to replace some of the problem-solving labs with experiential learning labs. The student appeared to appreciate the opportunity for hands-on learning. Anecdotal evidence indicated they were useful in solidifying key concepts. It was easy to get students to engage in the Concrete Experience and Active Experimentation portion of the exercises. Their engagement with Reflective Observation and Abstract Conceptualization was less successful for a number of reasons. They include the length of time required for the Concrete Experience and Active Experimentation and the instructor's unfamiliarity with the full scope of the modules. In several applications, the students were asked to complete the Reflective Observation and Abstract Conceptualization learning as homework assignments after the hands-on lab. This post-lab work was not especially effective. Proposed improvements include shortening the Concrete Experience and Active Experimentation portions of the labs allowing time for Reflective Observation and Abstract Conceptualization to be conducted in class."

Faculty feedback 2:

"Many students struggled when they solved 3D static questions, which may be because students were confused about coordinate and 3D static problems are more complicated than 2D static problems in general. The developed 3D equilibrium module consists of the actual 3D hands-on activity part and a handout with the problem statement and activity guidance. During the lab class, students could see the actual location of the given points and how the forces were acting on each cable. Also, the handout guided students to solve the given problem step-by-step. This hands-on activity helps not only students learn how to solve 3D problems but also how they can approach them when they deal with 3D problems. To encourage the participation of students, I made this hands-on activity a bonus point opportunity since it was a demo session for my class. Almost all students submitted answers and received bonus points. Feedback from students was positive and students responded that the class was helpful to understand the concept. I will implement this type of hands-on activity as a normal lab session and will try other than the 3D module."

Faculty feedback 3:

"The experiential learning modules have been easily conducted in the classroom while covering the corresponding topics. They allowed students to see the Dynamics problems in the real world and challenged them to think analytically. The problem was understood better by the students and they were all engaged during the hands-on activities. According to my observations, teamwork and communication were other important aspects of the activities. The students communicated well actively participated in the discussion, and brought different perspectives to the possible causes and consequences of the problems. I believe their engineering skills and knowledge have been improved during the hands-on experimentation. I recommend increasing the number of experiments for Dynamics and developing similar hands-on activities for junior-level classes as this would increase the retention rates in the Engineering Department at Angelo State university."

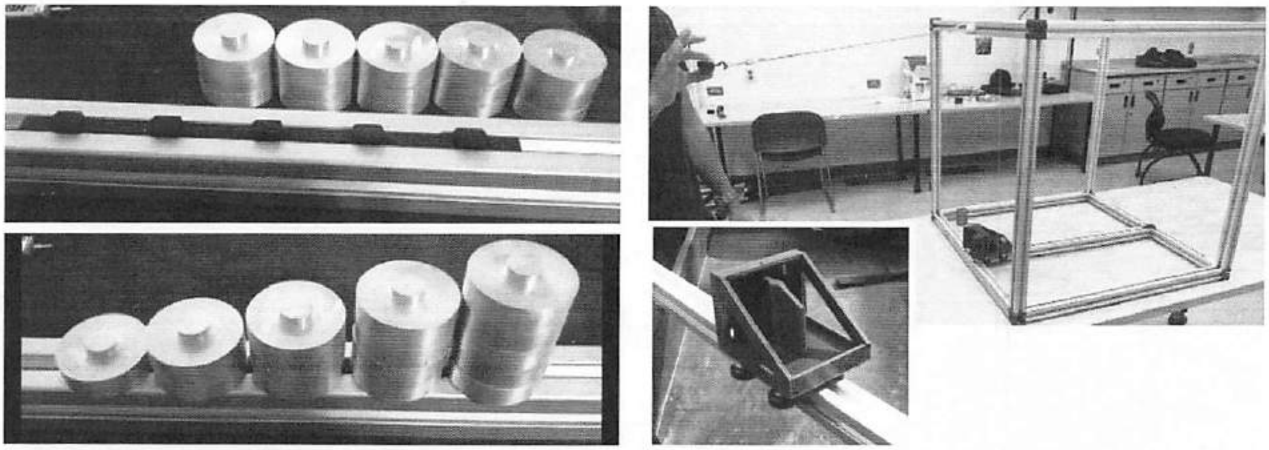


Figure 2: work-in-progress for additional modules, (left) 2D rigid body equilibrium with distributed loads, (right) Mechanics of Impact and coefficient of restitution

Work In Progress

Additional modules are under development. One of the modules in progress for Statics is the 2D rigid body equilibrium with the distributed load. Aluminum rods are cut into equal size pieces and machined to create a built-up edge on the top and a hole at the bottom for staking as shown in Figure 2 (left). An adapter is 3D printed to mount the aluminum weights on the extrusions to mimic distributed loading conditions. The module for dynamics is Mechanics of Impact and Coefficient of restitution as shown in Figure 2 (right). A 3D-printed carriage can slide on the extrusion after an impact by a swinging weight. Student and faculty feedback is being considered to improve the existing handouts and to create new module handouts.

Summary and Conclusions

The survey results of hands-on experiential learning applied to Statics and Dynamics at Angelo State University for the Spring and Fall 2022 semesters are reported. The survey suggests that students and faculty in both courses agree that a concept is learned better if it can be observed using a physical model. The student's response is higher in Statics when compared to Dynamics. The surveys and faculty feedback indicate the dynamics learning modules may be revised for clarity, and that making them a bit simpler may improve evaluation. Two new learning modules are provided in the appendix section for adoption.

References

1. Kaul, S., & Sitaram, P., 2013, Curriculum Design of Statics and Dynamics: An Integrated Scaffolding and Hands-On Approach. In Proceedings of the 120th ASEE Annual Conference.
2. Marra, R. M., Rodgers, K. A., Shen, D., & Bogue, B. (2012). Leaving engineering: A multi-year single-institution study. Journal of Engineering Education, 101(1), 6-27.
3. Osta, A., & Kadlowec, J. (2016, June). Hands-on project strategy for effective learning and team performance in an accelerated engineering dynamics course. In ASEE Annual Conference and Exposition, Conference Proceedings

(Vol. 2016).
4. Ferri, A. A., & Ferri, B. H. (2016, June). Blended Learning in a Rigid-Body Dynamics Course Using On-Line Lectures and Hands-On Experiments. In ASEE Conference and Exposition, New Orleans, LA.
5. Haque, M. S. (2021, July), *Work in Progress: Hands-on Engineering Dynamics using Physical Models in Laboratory Sessions* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. https://peer.asee.org/38165
6. Newberry, B. L. (2003). Hands-on Learning in Engineering Mechanics using Layered Beam Design. age, 8, 1.
7. Sirinterlikci, A., & Kerzmann, T. L. (2012). Integrated Hands-on Dynamics Laboratories in the Classroom. In American Society for Engineering Education. American Society for Engineering Education.
8. Pionke, C. D., Parsons, J. R., Seat, J. E., Weber, F. E., & Yoder, D. C. (1999). Integration of statics and particle dynamics in a hands-on project-oriented environment. age, 4, 1.
9. Avitabile, P., Goodman, C., Hodgkins, J., White, K., Van Zandt, T., Hilaire, G. S., ... & Wirkkala, N. (2004, June). Dynamic systems teaching enhancement using a laboratory-based hands-on project. In Proc. 2004 ASEE Annual Conference.
10. Avitabile, P., Van Zandt, T., Hodgkins, J., & Wirkkala, N. (2006). Dynamic systems teaching enhancement using a laboratory-based project (RUBE). In Proc. 2006 ASEE Annual Conference.
11. Self, B. P., Widmann, J., Prince, M. J., & Georgette, J. (2013, June). Inquiry-based learning activities in dynamics. In Proceedings of the 2013 ASEE Annual Conference & Exposition.
12. Kypuros, J. A., Vazquez, H., Tarawneh, C., & Wrinkle, R. R. (2011). Guided discovery modules for statics and dynamics. American Society for Engineering Education.
13. Kolb, D. A. (2014). Experiential learning: Experience as the source of learning and development. FT press.
14. Nakazawa, T., Matsubara, M., Mita, S., & Saitou, K. (2014). Teaching materials and lesson plans for hands-on mechanics education. Experimental Techniques, 38(6), 72-80.
15. Vernon, J., Finelli, C. J., Perkins, N. C., & Orr, B. G. (2015). Piloting i-Newton for the experiential learning of dynamics. In Proceedings of the 2015 American Society of Engineering Education Annual Conference and Exposition.
16. Hertz, J, Daviero, 2019, We Own This: A Class Patent System as Experiential Learning, In ASEE Conference and Exposition.
17. Battistini, A., Haque, M. S., Guzman, S., & Sims, M. (2022, June). Identification and Creation of Experiential Learning Modules for Engineering Statics and Dynamics (Work in Progress). In *2022 ASEE Annual Conference & Exposition*.
18. Hibbeler, R. C., Engineering Mechanics: Dynamics, 14th Ed and Solution Manual. 2016.

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Survey data was conducted with the approval of the X 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.

Appendix A: Statics Learning Module

Laboratory 3: Experiential Learning Module for Principle of 3D Static Equilibrium
Task 1 – Concrete Experience **Learning Objective:** Model the following problem using the 3D coordinate model and measure the equilibrium forces in each of the three cables.

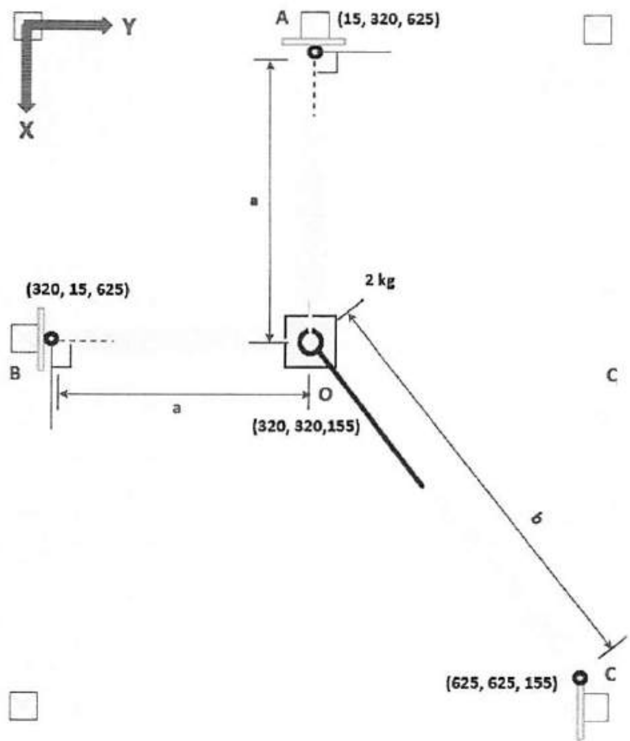

Figure 1: Problem Layout

A. Using the adaptive 3D coordinate model, assemble the three force gauges, the provided yellow cables, and the keyring as shown in Figure 1 (see also Figure 2 and Figure 3).
   Note: The cable and gauge at point C should be parallel to the floor.
B. Zero each force gauge using the white plastic nut located at one end prior to attaching the 2 kg mass.

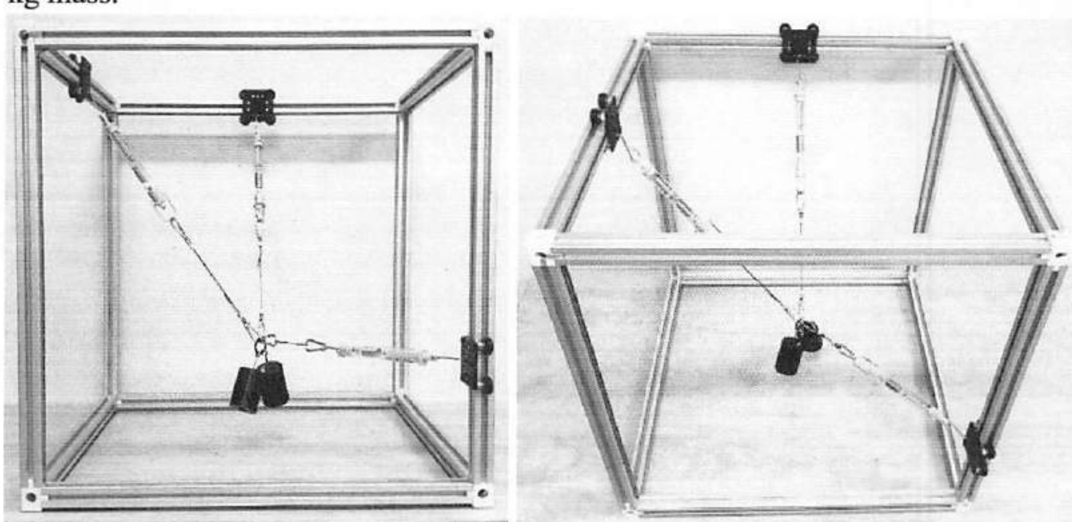

Figure 2: Front View (left) & Top view (right) - Fully Assembled for Analysis

C. Using the weights given, carefully hang 2 kg of mass on the keyring.
   Note: For accurate results, make sure points A and B create a right angle to each other keeping the 2 kg mass in the center of the model along the X and Z axes.

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_{AO}: ________________N
   - Experimental T_{BO}: ________________N
   - Experimental T_{CO}: ________________N

Task 2 – Reflective Observation

Learning Objective: Determine the theoretical forces by performing vector analysis, and compare the results with the experimental values.

A. Using vector analysis, find the following for each cable:

Position Vectors:
- $r_{OA:}$ ______________________________
- $r_{OB:}$ ______________________________
- $r_{OC:}$ ______________________________
- $r_{OD:}$ (0, 0, -5)

Position Vector Magnitudes:
- $|OA|$: __ mm
- $|OB|$: __ mm
- $|OC|$: __ mm
- $|OD|$: 5 mm

Unit Vectors (Use variables for each cable):
- $\vec{U}_{OA}$: ______________________________
- $\vec{U}_{OB}$: ______________________________
- $\vec{U}_{OC}$: ______________________________
- $\vec{U}_{OD}$: < 0i, 0j, -1k>

Force Vectors:
- F_{OA}: ______________________________
- F_{OB}: ______________________________
- F_{OC}: ______________________________
- F_{OD}: <0i, 0j, -19.62k)

B. Utilize static equilibrium equations to solve for the tensions in cables OA, OB, and OC. (
   - Theoretical T_{OA}: ________________N
   - Theoretical T_{OB}: ________________N
   - Theoretical T_{OC}: ________________N
   - Theoretical T_{OD}: 19.62 N

C. Compare Theoretical findings with Experimental and report percent error.
   - % error T_{OA}: ________________
   - % error T_{OB}: ________________

- % error T_{oc}: ________________
- % error T_{od}: 0%

Task 3 – Abstract Conceptualization
Learning Objective: Discuss the effect of changing components on the current system.

A. As a group, discuss and record predictions of changes in the system when each of the following is considered:
   a. More/Less Mass (will change be linear?):
   ____
   ____
   b. Shorter OC Cable:
   ____
   ____

Formulas: **Sum of Forces:** $F_x = 0$ $F_y = 0$ $F_z = 0$	**Position Vector:** $r_{AO} = r_O - r_A$	**Unit Vector:** $u_{AO} = \frac{r_{AO}}{\lvert r_{AO} \rvert}$	**Force Vector:** $F = F\hat{u}$

Percent Error: ($Tension_{theo.}$ - $Tension_{exp.}$) / $Tension_{theo.}$ * 100 = % Error

Task 4 – Active Experimentation:
Learning Objective: Prove the effect of changing components on the current system.

A. Replace the OC cable with the singular blue clip provided. How does the change in position of the mass affect the forces of F_A, F_B, and F_C?
   ____
   ____
   ____

B. Use the shorter cable provided and google sheet to solve the force magnitudes.

Appendix B: Dynamics Learning Module

Laboratory 5: Experiential Learning Module for Dependent and Relative Motion of Particles

Task 1: Observe the **dependent** and **relative** motion of particles

Learning Objective: To observe the relative and dependent motion of pulley system

I. Assemble the pulley system as shown in figure 1-1, where the mass A = x kg, B = y kg, and C = z kg.

II. Release mass A and observe the relative motion of mass B and C compared to mass A. Are the masses B and C moving faster or slower than A?

III. Redo "step II", however, this time focus on observing any dependency of the motion of the masses A, B, and C on each other. Add a small mass to mass B and observe does it change the motion of the system compared to "step II" or remained the same.

IV. Next, remove a small mass from mass C and observe does it change the motion of the system compared to "step II" or remained the same.

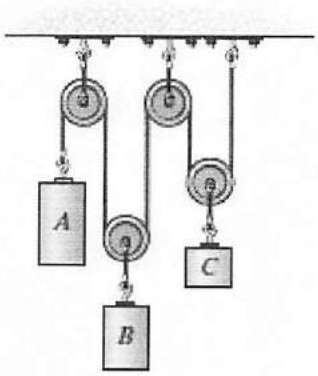

Fig. 1-1: weight and carriage problem [18]

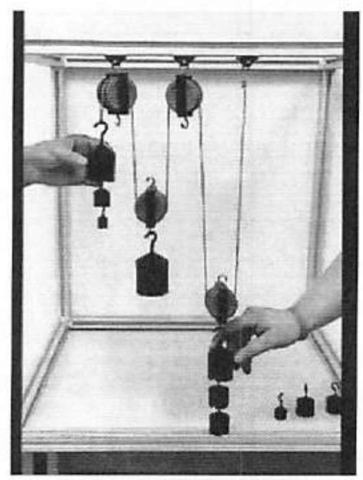

Fig. 1-2: Module assembly

Task 2: Reflective observation of the relative and dependent motion of masses in the pulley system.

Learning Objective: To relate relative motion with real-world scenarios.

A. Based on your observation from Task 1, why do you think mass B is moving faster/slower than mass A?

B. Based on your observation from task 1, why do you think mass C is moving faster/slower than mass A?

C. Assume the center of the fixed pulleys as the distance measuring point, while mass A is going down, masses B and C going up or down? why?

D. While the position of masses is changing, however, the total length of the cord connecting all pulleys is not changing. Can you represent the total length of the cord in terms of the variable position of the masses S_a, S_b, S_c. ?

E. Based on your observation from Task 1 (Step I & II), would you agree that the motion of one mass is dependent on the other two masses because they are connected by a cord?

Task 3: Abstract Conceptualization and Validation of Dependent motion
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. Since the total length of the cord is constant, the position of masses A, B, and C are dependent on each other. The dependent motion equation may be generated from this concept. (column 1- 1st row, and fig 1-1). Taking 1st derivative with respect to time (t) gives the dependent velocity equation.

B. Using vector addition, the position of body B measured relative to another body A is denoted by the relative position vector (2nd column - 1st row). Taking 1st derivative with respect to time (t) gives the relative velocity equation.

Dependent motion analysis	Relative motion analysis
$S_a + 2S_b + 2S_c = l$ $v_a + 2v_b + 2v_c = 0$	$r_{B/A} = r_B + r_A$ $v_{B/A} = v_B + v_A$

Task 4: Challenge Problem: Perform a similar experiment using the module
Learning Objective: To recognize and solve problems involving absolute dependent and relative motion analysis.

Redo the test described in Task 1, this time use a digital stopwatch and a camera in slow motion to record the motion of the masses A, B, and C. Take the measurement of the position of pulleys A, B, & C from the fixed pulleys before release. The purpose of the video is to analyze the motion of the masses and to determine the time taken to come to a stop after releasing from rest. Also, measure the traveled distance (s) of the masses after they came to stop. (Note: It would be easier if you use a cell phone stopwatch visible in the camera, and start the stopwatch a little earlier than releasing the mass A. The bigger screen of a cell phone in the slow-motion video will give you near-accurate time measurement) Follow the steps below:

1) Use the slow-motion video to determine the traveled distance of mass A and the time of travel to determine its velocity. (It would be easier if you can attach a 2-foot ruler to the frame visible in the camera) Do the same for masses C and B to determine their average velocity from the same video.
2) Use the dependent motion equation defined in Task 3, to determine the velocity of mass B by plugging the velocity found in the previous step for mass A and C. Compare this value with the velocity of B found in the previous step. Are the values close or far off? Why?
3) Use the relative motion equation defined in Task 3, and find the relative velocity of mass B with respect to mass A?