A Novel 2D Vectors Hands-on Lab Exercise for a First Year Engineering Mathematics Laboratory

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Overview

- Background
- Motivation
- Two-Link Arm Apparatus
- Student Feedback
- Summary

Background

- The six-year graduation rate from NCE ranges between 55% and 58%
- A key detrimental factor is the high failure rate (35-40%) in first year mathematics courses
- Close to half of our first-year students do not place into Calculus-I!
  - They enter a labyrinth of remedial courses which are
    - Often ineffective
    - Don't lead to a normal plan of study

The Wright State Model

- Wright State University has developed a model that attempts to help engineering colleges increase retention rates

- The model was developed with NSF funding and has been tried at or adopted by 40+ universities

- See https://www.aacu.org/sites/default/files/files/tides/Klingbeil.pdf for statistics and details

The Wright State Model

- The Main Idea: offer a first-year course that provides an application-oriented, hands-on introduction to engineering mathematics

- Increase student retention, motivation, and success in engineering
  - In Wright State University 71% of the engineering students who took the course completed their degree in 4 years
  - Those who did not had a completion rate of 40%

ENGR101 Course Framework at NJIT

- 4-credit course
- 3 hours lecture, 1.5 recitation, 1.5 hour lab
- 2-3 combined Common Lectures – 50-70 students
- Multiple sections of Lab and Recitation – 20-25 students
- Student Population: Students placed into pre-calculus courses

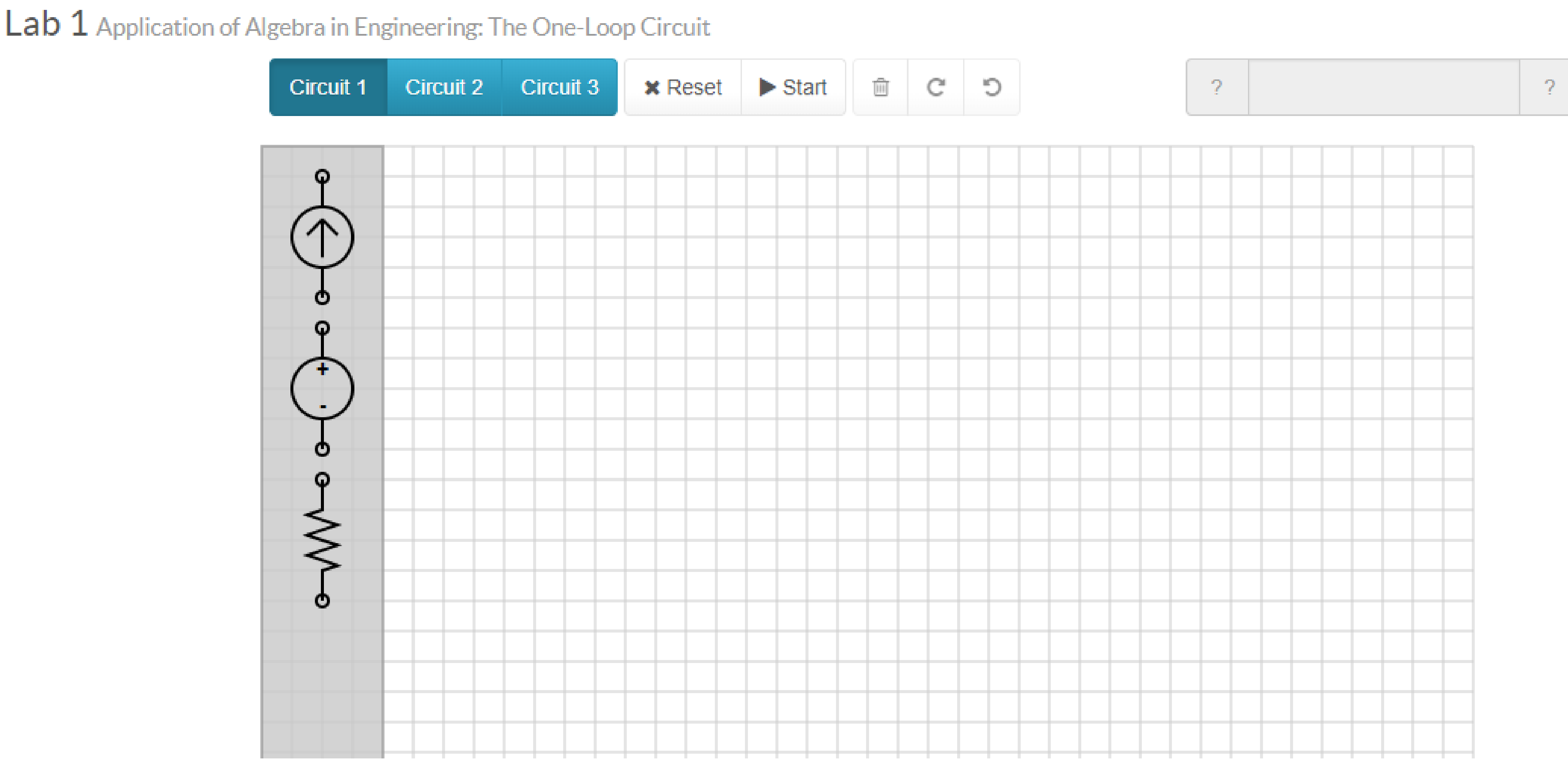
ENGR101 Lecture Syllabus

Week 1	Application of Algebra in Engineering – Linear Equations and Quadratic Equations
Week 2	Application of Trigonometry in Engineering - One and Two-Link Planar Robots
Week 3	Introduction to Vectors, Free Body Diagrams
Week 4	**Exam#1**, Introduction to Complex Numbers in Engineering
Week 5	Sinusoids and Harmonic Signals in Engineering
Week 6	Systems of Equations and Matrices in Engineering
Week 7	Introduction to Derivatives in Engineering Application of Derivatives in Dynamics
Week 8	**Exam #2**, Application of Derivatives in Electrical Circuits
Week 9	Application of Derivatives in Mechanics of Materials
Week 10	Application of Integrals in Engineering Application of Integrals in Statics
Week 11	Application of Integrals in Dynamics
Week 12	**Exam #3**
Week 13	Applications of Integrals
Week 14	Summary and Review

ENGR101 Lab Syllabus

Week	Lab Topics
1	Introduction to MATLAB and Basic tools used in MATLAB
2	Built-in MATLAB Functions. Manipulating Matrices in MATLAB
3	Plotting in MATLAB
4	Lab #1: Application of Algebra in Engineering: The One-Loop Circuit (Virtual Lab)
5	**Lab #1A: Application of Algebra in Engineering: The One-Loop Circuit (Physical Lab)**
6	Lab #2: Trigonometric Relationships in One and Two-Link Planar Robots (Virtual Lab)
7	Lab #3: Measurement and Analysis of Harmonic Signals (Virtual Lab)
8	**Lab #4: Application of Vectors and Trigonometry to Analyze a Two-Link Robot (Physical Lab)**
9	MATLAB: User Controlled Input and Output, Symbolics
10	**Lab #5: Systems of Equations in Engineering: The Two-Loop Circuit (Physical Lab)**
11	MATLAB: Selection Structure and Logical Functions
12	Lab #6: Derivatives in Engineering: Velocity and Acceleration in Free-Fall (Virtual Lab)
13	Lab #7: Integrals in Engineering: Work and Stored Energy in a Spring (Virtual Lab)
14	Make Up Lab Week

Virtual Lab Example



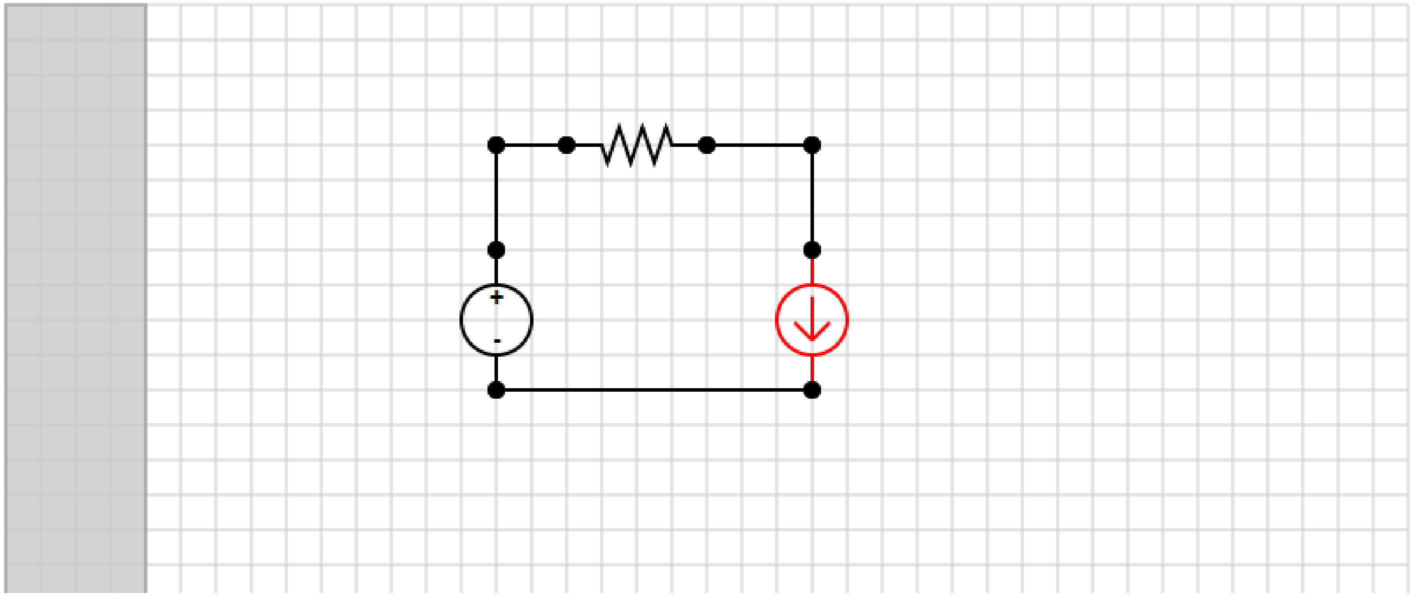
Virtual Lab Example

Lab 1 Application of Algebra in Engineering: The One-Loop Circuit

Circuit 1 | Circuit 2 | Circuit 3 | ✖ Reset | ▶ Start

AM1 | 0.09996075854929441 | A

Circuit complete! Check the value of the ammeter

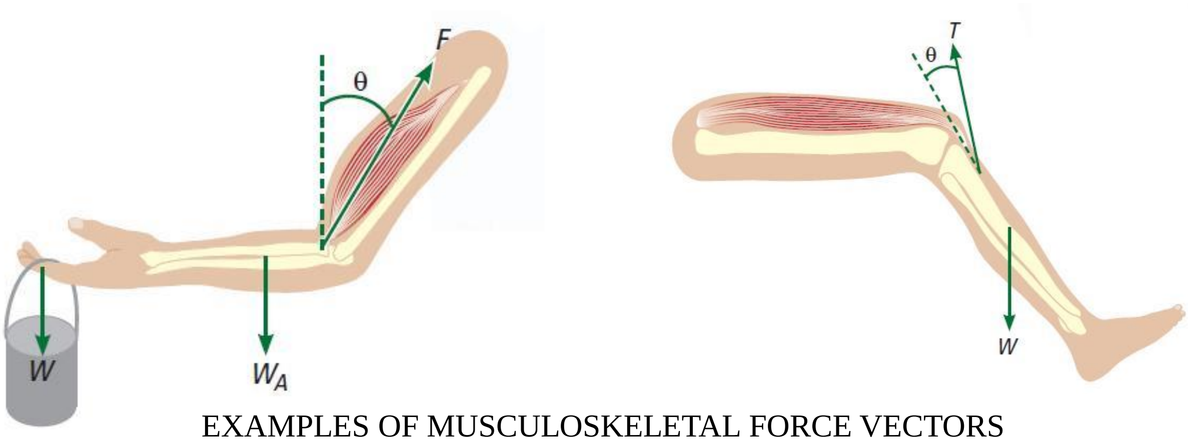


Motivation

- All engineering majors require the ability to resolve vector quantities
  - Force
  - Position
  - Velocity
  - Acceleration
  - Electric and magnetic fields
- Students placed in pre-calculus courses often struggle to visualize and resolve vector quantities into their component form.
- Introducing these concepts early in an introductory engineering math course in conjunction with a simple hands-on lab offers an opportunity to reinforce these fundamental concepts.

Motivation

- The musculoskeletal system presents a number of examples for which force vectors can be effectively studied.
- For example: the mechanics of the arm, hip, knee, and ankle. The human arm is also an example of a two-link robot.



EXAMPLES OF MUSCULOSKELETAL FORCE VECTORS

Two-Link Arm Apparatus

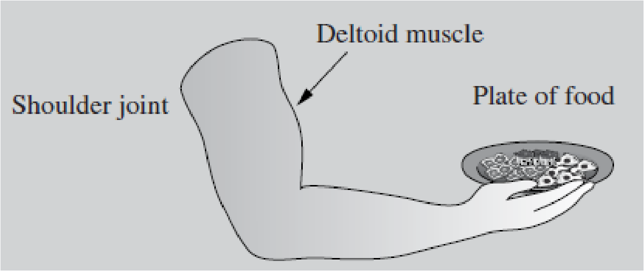
- A human arm and bicep muscle model is used to demonstrate the application of vectors in engineering and the law of sine and cosine to find muscle length, muscle attachment angle, and end position distance.
- PASCO Scientific offers a human arm model which simulates the bicep and triceps muscles using strings.
- By pulling on a force sensor that is attached to a string, the tension in the string can be measured.
- The string tension creates a moment about the elbow joint which lifts a weight placed in the hand.

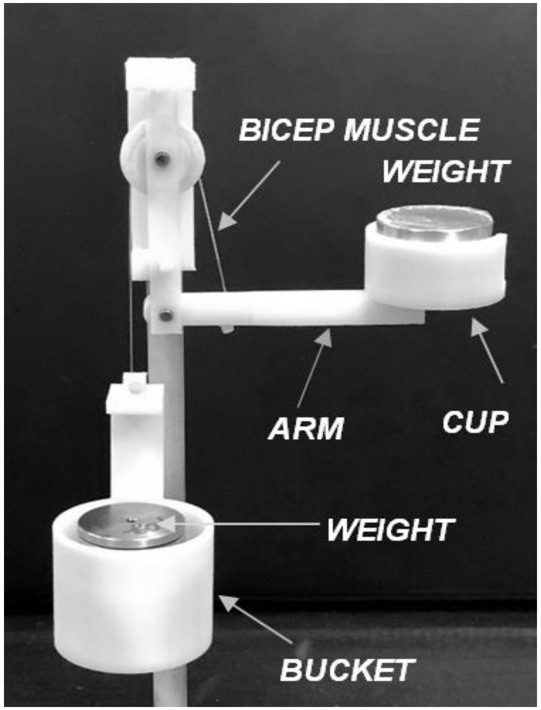
PASCO SCIENTIFIC HUMAN ARM MODEL

Two-Link Arm Apparatus

- Here we present a two-link robot-arm-muscle model that can be cheaply fabricated and assembled from 3D printed parts.

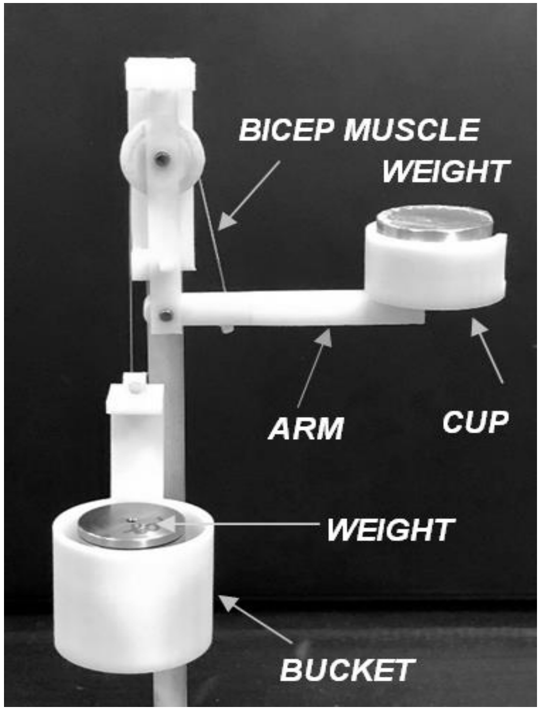
- Adding weights in the bucket creates the bicep muscle force that enables the arm to lift the load in the hand.





Two-Link Arm Apparatus

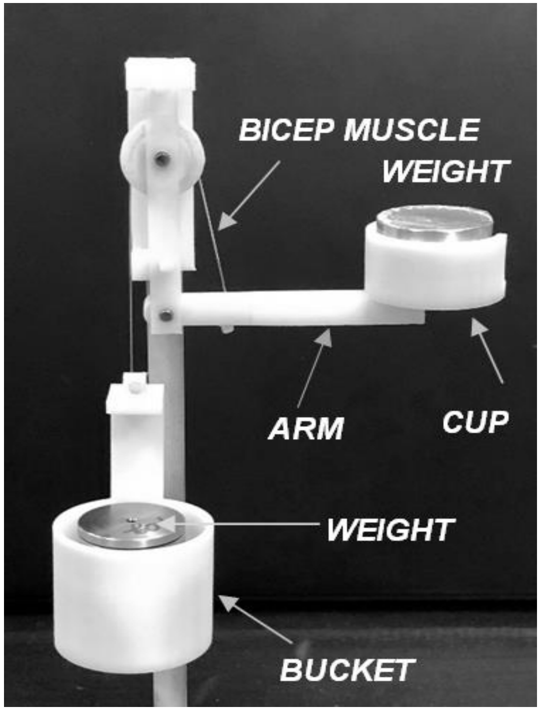
- As opposed to using a force sensor, by physically adding the weights into the bucket students can directly measure the force.
- The use of weights to manually load and collect data can give insight that is often lost with more automated models used for data acquisition.



Two-Link Arm Apparatus

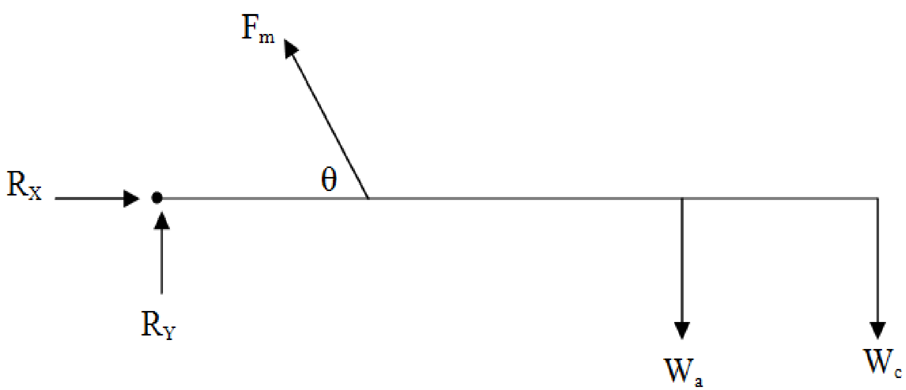
- The goal for the students is to balance the weights in the bucket and in the cup to achieve a state of equilibrium with the arm in the horizontal position.

Weight in the cup (g)	2	5	10	20	25
Weight in the Bucket (g)					

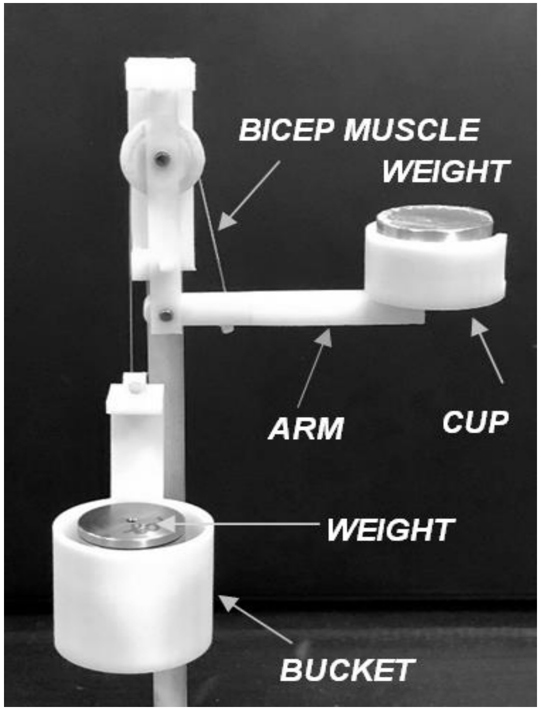


Trigonometry Review – Reaction Forces

- Using the free body diagram, the reaction forces, R_x and R_y are calculated



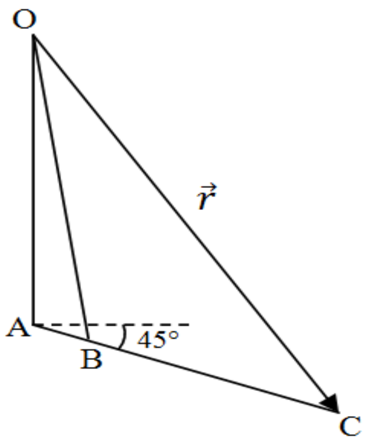
MUSCLE-ARM FREE-BODY DIAGRAM



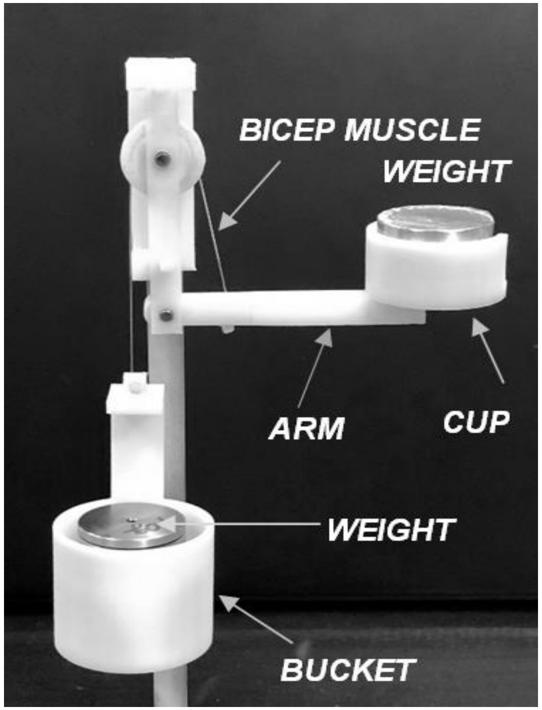
Trigonometry Review – Law of Cosines

- As an additional exercise, students are asked to balance the weights such that the arm is positioned at 45° below the horizontal. In this position the muscle length $\overline{OB}$ is calculated using the law of cosines.

$$\overline{OB}^2 = \overline{OA}^2 + \overline{AB}^2 - 2\overline{OA}\,\overline{AB}\cos 135^0$$



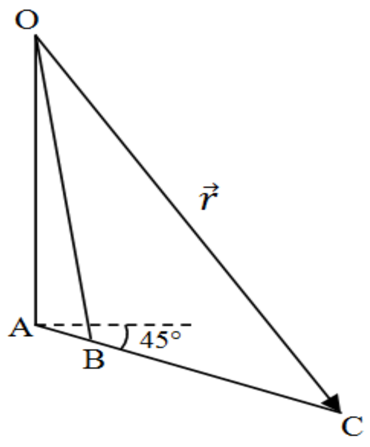
TWO-LINK ROBOT WITH 135^0 ANGLE BETWEEN THE LINKS



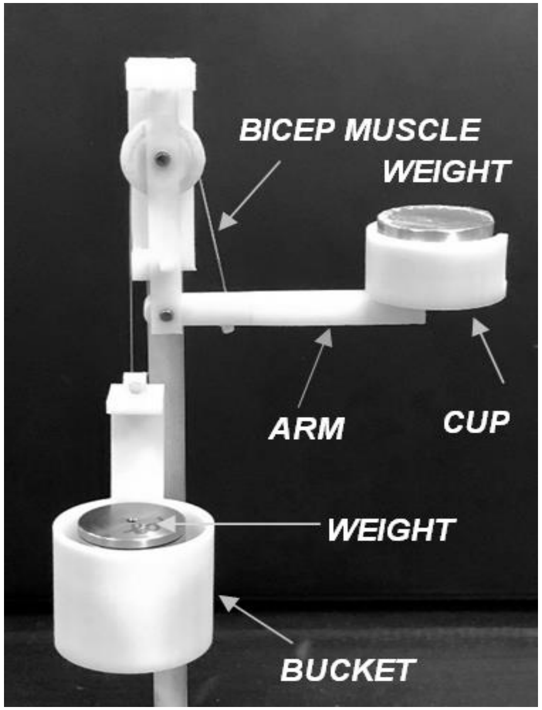
Trigonometry Review – Law of Cosines

- The forward kinematics equation to find the components of $\vec{r}$ is given by:

$$r_x = \overline{AC}\cos 45^0$$
$$r_y = \overline{OA} + \overline{AC}\sin 45^0$$



TWO-LINK ROBOT WITH 135^0 ANGLE BETWEEN THE LINKS



Student Feedback

- Student feedback on physical, instead of virtual simulation (on-computer), labs was collected through a survey at the end of the semester.
- The question specifically asked – “Please comment on the physical labs that you did. Did those help you understand the topic better than the virtual labs?”

Student Feedback

- Positive Responses:
  - I believe doing the lab in person instead of virtually helped me understand the concept more. This is the case because I am a visual learner.
  - Yes, working hands on for me is a better experience. It is clearer because I am actually tweaking with the real-life problem.
  - Yes (3)
  - The physical labs helped me to understand the topic better compared to the virtual labs because I could actually see and build upon what's going on.
  - Yes, the physical lab is a great way to see what is actually going on in the virtual labs. It gives students a hands-on view about how the problems work rather than just putting in a number on the virtual lab.
  - Physical labs were definitely better than the virtual labs. It helped me understand topics overall much better. (3)
  - Physical Labs gave a better representation of the lab as compared to virtual labs.
  - I think that the both were beneficial. But, the Physical Lab is a better implementation for learning for the career.

Student Feedback

- Neutral Responses:
  - The physical labs helped me understand the course material just as well as the virtual labs.
  - It helped a little bit but not that much.
  - I knew most of the physical lab material from my FED 101 class, so I didn't really learn much more but nevertheless, the physical lab was a nice change.

- Negative Responses:
  - The virtual labs were definitely much easier to understand than the physical labs.
  - They helped only a few certain majors.
  - They were fun, but they didn't apply to my major and they weren't well explained enough.
  - I was able to understand both labs equally, physically or virtually. I found the virtual lab were a bit more intuitive and easier to complete.

Summary and Future Plan

- A hands-on lab has been presented that uses an inexpensive 3D printed arm-muscle model to demonstrate applications of vectors and trigonometry for use in introductory engineering mathematics courses. Upon completing the lab, students should be able to:
  - Understand 2D vectors and apply them to engineering problems.
  - Understand and apply the law of cosines.
  - Be able to perform the direct kinematics for two-link robot.

- Overall, students liked the experience of reviewing the topic of vectors and trigonometry with a hands-on lab experiment and we plan to refine it further and run this again in Fall 2018 semester for a much bigger student population

Questions? or comments!