Providing Inexpensive Lab Apparatus to High School Physics Labs Using Recycled Components

Senior Project

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By

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Abstract

Many people think of Science and Mathematics upon hearing the term STEM, while in reality this term includes Science, Technology, Engineering, and Mathematics. Therefore, it is crucial to implement STEM Education within the educational system as early as high school. The reasons behind the need for STEM Education are discussed according to Reeve's point of view. Also, the six characteristics that are required for any great STEM lesson are discussed as mentioned in Jolly's article. Although a solid physics curriculum can provide a foundation for the integration of the STEM areas, it is often ignored by students in high school. One of the reasons for this is the lack of funding which leads to the shortage of physics lab apparatus available for the students to apply learned concepts. The focus of the service learning project is to provide an example of how inexpensive and recycled components could be used in the assembly of physics lab apparatus that would otherwise cost a lot of money to purchase.

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Introduction

When people hear the word STEM, often times they associate it to the areas of Science and Mathematics. This could be due to the fact that the areas of Science and Mathematics are the most recognized, and funded, fields when it comes to STEM education (White). In reality, STEM is more than just Science and Mathematics. The Term 'STEM' stands for Science, Technology, Engineering, and Mathematics. These terms are well known and defined within the STEM society, the definitions of these terms are:

> **Science:** the systematic study of the nature and behavior of the material and physical universe, based on observation, experiment, and measurement, and the formulation of laws to describe these facts in general terms.
> **Technology:** the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science.
> **Engineering:** the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, buildings, mines, ships, and chemical plants.
> **Mathematics:** a group of related sciences, including algebra, geometry, and calculus, concerned with the study of number, quantity, shape, and space and their interrelationships by using a specialized notation (White).

While Science and Mathematics are well known when it comes to STEM, Technology and Engineering are often times ignored. This might be due to the fact that Technology and Engineering lack the proper lever of representation, and possibly funding, when it comes to education (White). Therefore, and due to the fact that Engineering and Technology are two of the fields that are constantly growing within

STEM Careers, Students need to be exposed to all areas of STEM and get educated on their importance and relation to real life as early as high school through a proper STEM education.

STEM Education and Physics

According to Reeve, STEM Education is defined as "a teaching and learning approach in which science, technology, engineering, and mathematics (STEM) are purposely integrated" ("Science, Technology"). This definition suggests that an effective STEM course is not one that necessarily focuses on one, or all, of the four fields of STEM, but rather one that exposes students to these fields and shows them how the four fields of STEM are interrelated and how one field cannot survive without the use of the others. Also, looking at today's growing nations, and the competition among them for being the most advanced, one can see the importance of STEM education and its integration within the educational system.

Within his presentation, Reeve gives six reasons to why STEM Education is crucial and needs to be exposed to students as early as possible. These reasons are summarized as follows. The reality of globalization and how STEM-based education can provide us with the foundation needed to remain competitive and as technologically advanced as possible among today's nations. Innovation is crucial, and in today's society, STEM is involved in nearly all developmental stages of beneficial inventions. A professional working within the STEM area is integrated in the process of solving many of the emerging world's problems. STEM education has the potential to get more students interested in pursuing careers within the STEM fields, especially when it comes to the fields of technology and engineering. A proper STEM education will provide students with a hands on experience in problem solving as well as strengthening the four skills known as the '4Cs', these are 'Critical Thinking, Collaboration, Communication, and Creativity'. The final reason that Reeves conveys for the importance of STEM education is that it can provide students with a better understanding of the four fields of STEM and an opportunity to see how these fields are inter-connected ("Science, Technology").

In order to gain the interest of the students and to get them excited about participating in STEM education, a well-planned and delivered STEM lesson needs to be executed. According to Jolly in her article "Six Characteristics of a Great STEM Lesson", a good STEM lesson is required to possess six characteristics implemented in its core. These characteristics are:

1. Focus on "real-world issues and problems" (Jolly), this will give the students a chance to see how STEM relates to everyday life and will make them more motivated about the subject.
2. Utilization of the Engineering Design Process, EDP (Jolly). EDP is a process, very similar to the scientific method, which professionals in technology and engineering fields use when tackling issues emerging in life. When using EDP "students define problems, conduct background research, develop multiple ideas for solutions, develop and create a prototype, and then test, evaluate, and redesign them" (Jolly). So, since most STEM students are already familiar with the Scientific Method, implementing a similar method of solving problems within a STEM lesson will show the students how science is related to technology, engineering, and mathematics.

3. Allowing students to get involved in "hands-on inquiry and open-ended exploration" (Jolly). This allows for the learning process to be student-led and gives the students an opportunity to collaborate with others in coming up with solutions regardless of the constraints presented to them like a time frame or materials availability.
4. Encouragement of teamwork amongst students (Jolly). This will allow students to work with others who are more likely to be of different background or studying a different field of STEM from the student. This allows for the introduction of new ideas and points of view that allows for the integration of the different fields of STEM in producing a solution for a common problem.
5. Applies the concepts learned in math and science courses to the areas of technology and engineering (Jolly). This will again allow students to see the interrelation between the four fields of STEM.
6. Gives the chance for multiple right answers to emerge and views failure as an integral part of the learning process (Jolly). This prevents students from believing that there is only one way of thinking about a problem and provides them with the courage to think outside of the box and not be discouraged by failure attempts.

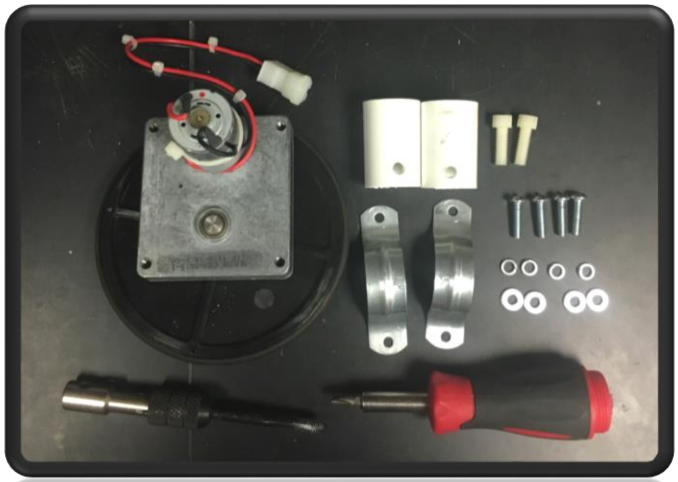
Looking at the courses taught that are considered to be part of STEM, very few integrate all the aspects of STEM within their lessons, especially in high school. Physics, one of these few courses, provides great integration of STEM within its courses. By allowing students to explore the physical universe around them and use their knowledge to create the means required to study this universe, while using technology, promotes exploration in creating possible solutions to emerging problems. Physics courses allow students with a great opportunity to see and implement all the aspects of STEM.

Although physics is one of the great examples of integrating all aspects of STEM, it is often times one of the most neglected courses of study, especially in high school. As a matter of fact, only about one third of high school students take physics ("Why Teach?"). One of the reasons that might be behind the neglect physics courses face, especially within economically challenged counties, is the lack of funding for physics labs. With most of the funding going to hardcore science and mathematics courses, very little funding goes into buying physics lab apparatus which most of the time is relatively expensive. So, with the lack of the means by which learned concepts in lecture could be applied to real life situations, students often times lose interest in the subject or decide to not even take the course. Therefore, this service learning project provides an example of one physics lab apparatus that could be assembled using inexpensive and even recycled components that would cost a fraction of what the actual apparatus would cost.

Centripetal Force Apparatus

This apparatus allows students to study the concept of centripetal force and have a hands-on experience in determining how gravity plays a role in centripetal force. It follows the same idea and mechanics of the chair swings ride found at any amusement park or fair.

Parts of assembly and their prices:



Component Description	Cost ($)
24 VDC, 45 RPM Gearhead Motor with Wheel, Used	9.95
0.5" PVC Couples (a count of two)	2.00
2 hole 0.75" Conduit Strap (a count of two)	2.00
Bubble Balance (a bag of ten)	4.00
30 V Regulated Power Supply	Available in most Physics Labs
Total Cost	~ 14.00

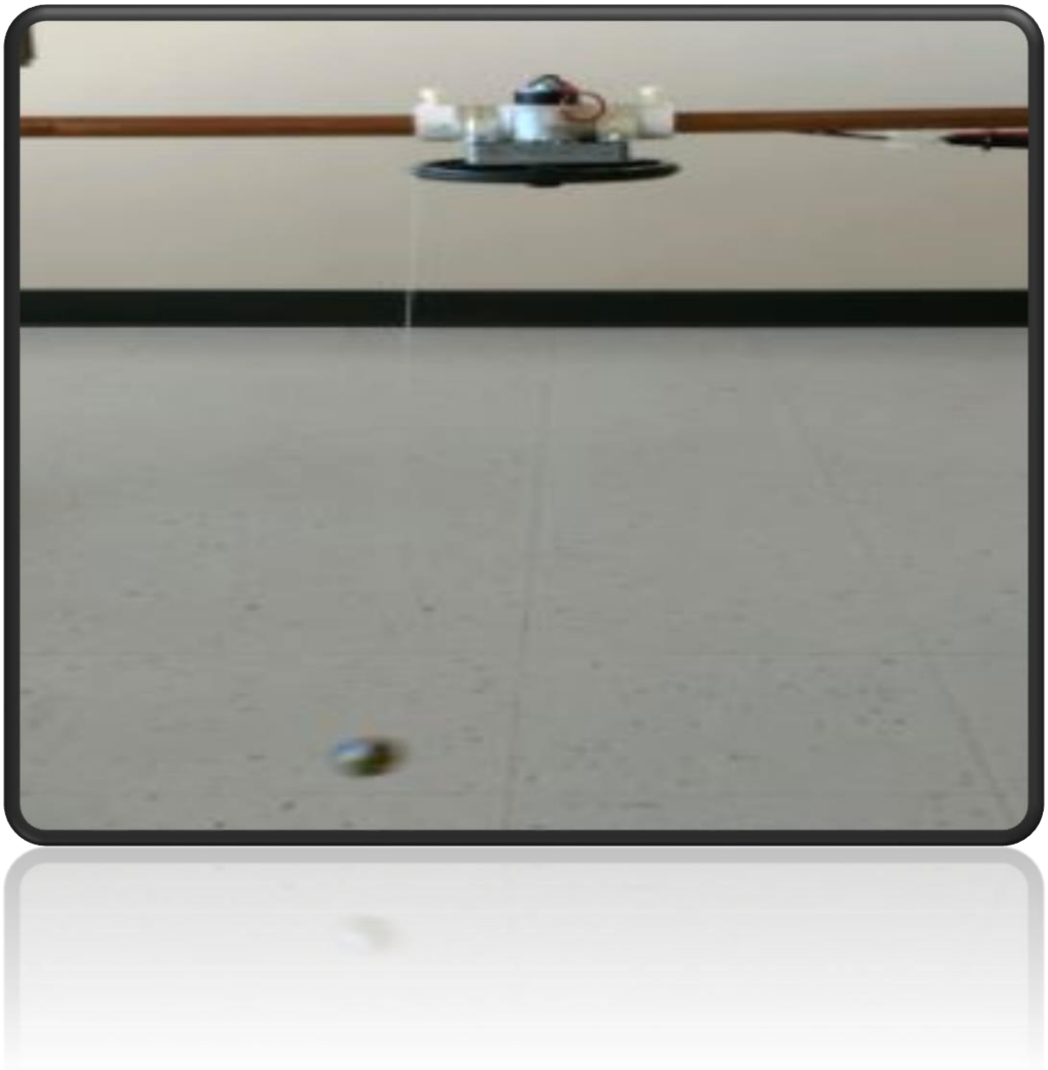
As it is shown in the above table, the overall cost of one of these apparatus is about $14, which is very inexpensive when compared to other apparatus produced by high named companies which often times would cost hundreds of dollars.

Process of Assembly:

- Using the conduit straps, attach the a PVC couple to each end of motor plate
- To the hole in the wheel tie one end of a 30 cm string
- Attach a rubber ball to the other end of the string

- Mount the system to a heavy metal beam attached horizontally to a fixed surface like a table and use one of the bubble balances to make sure the system is well balanced (it is crucial to balance the system in order to obtain realistic results).
- Using banana plugs attach the motor to the power supply.

The final product should look something like this,

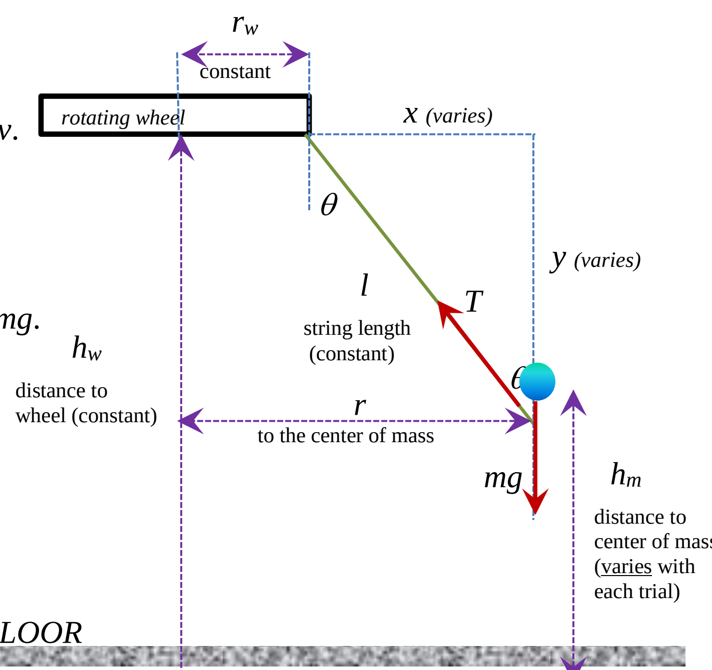


The following Lab manual is provided with the apparatus:

UNCP Centripetal Force Apparatus:
Circular Pendulum Experiment

This custom built UNCP apparatus uses a ten dollar gearhead motor with wheel. In this lab we will use the apparatus configured as a "circular pendulum".

Theory



The mass is moving in a circular orbit with speed v. According to fig. 1, with the forces shown by red vectors, we see that the horizontal component of string tension, $T\sin\theta$, supplies the centripetal force, F_c, and the vertical component of the string tension, $T\cos\theta$, is in equilibrium with the weight, mg.

1) $T\sin\theta = ma_c$

2) $T\cos\theta = mg$

Dividing eqn 1) by eqn 2) we obtain eqn 3) which can be rearranged to produce eqn 4).

3) $\tan\theta = \dfrac{a_c}{g}$

4) $a_c = g\tan\theta$

Note that the centripetal acceleration can be written in any of the following equivalent forms:

5) $a_c = \dfrac{v^2}{r} = \dfrac{(2\pi r/T)^2}{r} = \dfrac{4\pi^2}{T^2}r$

where T is the period, or time associated with one complete orbit, and r is the radius of motion as shown in fig. 1. In the experiment we must determine r from careful measurements. From fig. 1, note that the string length, l, the wheel radius (actually from rotational center to string attachment point), r_w, and the distance from the floor to the wheel, h_w , are all constant. So, they should be measured carefully and double checked! As we vary the speed (RPM) of the wheel, the radius of motion, and hence the angle, θ, will also vary. Therefore x, y, and h_m will also vary according to the following relations:

6) $r = r_w + x = r_w + l\sin\theta$

7) $\cos\theta = y/l \quad \Rightarrow \quad \theta = \cos^{-1}(y/l)$

8) $y = h_w - h_m$

Essentially, the centripetal acceleration, a_c, which we determined from theory (eqn 4, $a_c = g\tan\theta$), is experimentally determined from the following measurements (eqn 5 – summarized with experimental parameters),

9) $a_c = \dfrac{4\pi^2}{T^2}r \quad$ where $\quad r = r_w + l\sin\left[\cos^{-1}\left((h_w - h_m)/l\right)\right]$

Procedure:

1) Using the bubble level provided ensure that the wheel is as level as possible.
2) Carefully measure (and have lab partners confirm) the distance from the center of the wheel to the point where the string is attached. This is referred to the wheel radius, r_w. Record in the table below.
3) Carefully measure (and have lab partners confirm) the distance from the string's attachment point on the wheel to the center of the ball (mass). A length between 55 cm and 60 cm (from attachment to center of ball) is recommended. This is referred to the string length, l. Record in the table below.
4) Carefully measure (and have lab partners confirm) the distance from the wheel to the floor. This is referred to wheel height, h_w. Record in the table below.

fixed parameters	units in meters
wheel radius, r_w	
string length, l	
floor to wheel, h_w	

5) Inspect the power supply. Make sure the current settings are turned all the way clockwise (wide open). Make sure the voltage settings are turned all the way counter-clockwise (off). Turn on the power supply and slowly increase the voltage, at a rate of about 1 volt per 3 seconds, to about 20 V.
6) Once the swinging mass settles down into its steady state behavior (constant circular motion with no "modulation") do not readjust the power supply. Be careful to start at zero and count 10 revolutions! Carefully measure the period, T, which is the total time for 10 revolutions divided by 10. T = total time / 10. Record in the table below.
7) Carefully measure (and have lab partners confirm) the distance from the floor to the center of mass of the swinging object. Your lab instructor will demonstrate how to do this. This is referred to mass height, h_m. Record in the table below. Measure the period again (step 6) to ensure that it has not changed.
8) Repeat steps 6-8 in increments of *approximately* 2.5 V (20 V, 22.5 V, 25 V, 27.5 V, 30 V)

floor to CoM, h_m (m)	Period, T (s)	$\theta = \text{acos}((h_w - h_m)/l)$	$r = r_w + l \sin\theta$ (m)	$a_c = 4\pi^2 r/T^2$ (m/s^2)	tan θ	$g = a_c / \tan\theta$ (m/s^2)	% err

g_{avg} =	
σ_g =	
$g_{avg} \pm \sigma_g$ =	

Download the EXCEL template for the usual data analysis.

9) Graph the centripetal acceleration, a_c (y-axis) vs. $\tan\theta$ (x-axis). Your slope should be compared to the acceleration due to gravity, g - Recall equation 4) - $a_c = g\tan\theta$
10) A hand graph is also required.
11) Don't forget the required comparisons:
    a. agreement (or not) with g using tabular value (the mean) and standard deviation as error range
    b. % errors
    c. % differences

So, after studying the theory and going through the procedure, students will be able to calculate the acceleration due to gravity (g) as well as compare their calculated results to the known value of g to determine how accurate their execution of the procedure was and how to possibly improve it. This will be achieved using rulers, geometry and trigonometry, and Excel. Therefore, this apparatus provides a great example of the integration of STEM in one experimental procedure.

Conclusion

With the growing global competition in the need for technological advances, STEM education is a crucial element of education that needs to be introduced to the students and getting them interested in as early as high school. In his presentation, Reeve discusses the six important reasons behind the importance of having STEM education to students. In order to get students' attention and interest in STEM, a well-planned STEM lesson is required. In her article, Jolly talks about the six characteristics of a great STEM lesson. Through observation, it is shown how physics courses provide great integration and STEM education in lessons that possess most of the six characteristics discussed above. Even though physics shows great integration of STEM, it is often times one of the ignored subjects in high school. One of the reasons behind ignoring physics is the lack of funding for physics labs which in turn loses the gain of the students' interest in the subject due to the fact of the lack of apparatus where they can apply learned concepts in lectures due to their high prices. The apparatus presented in this article provides an example of how inexpensive and possibly recycled materials could be used to assemble Physics Lab apparatus that would otherwise cost hundreds of dollars to purchase.

Works Cited

Jolly, Anne. "Six Characteristics of a Great STEM Lesson." *Education Week Teacher*. Editorial Projects in Education, 29 Apr. 2016. Web. 27 Apr. 2017. <http://www.edweek.org/tm/articles/2014/06/17/ctq_jolly_stem.html>.

Reeve, Edward M. "Science, Technology, Engineering & Mathematics (STEM) Education Is Here To Stay." *International Technology Management Conference* (2012): n. pag. Web. 27 Apr. 2017. <http://www.stemedthailand.org/wp-content/uploads/2015/08/STEM-Education-is-here-to-stay.pdf>.

White, David W. "What Is STEM Education and Why Is It Important?" *Florida Association of Teacher Educators Journal* 1 (2014): 1-9. Web. 27 Apr. 2017. <http://www.fate1.org/journals/2014/white.pdf>.

"Why Teach?" *The Crisis in Physics Education*. Cornell University, 2011. Web. 27 Apr. 2017. <https://phystec.physics.cornell.edu/content/crisis-physics-education>.