Discovering the Magic of Mathematics: Mathemagics

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Abstract

Long enduring and emerging challenges in science, technology, engineering, and mathematics (STEM) education require innovative solutions to address the root causes of the problems. Only about 30% of our STEM students graduate in six years; many students either switch to a non-STEM major or drop out. Traditional classroom structures with presentation of abstract theories and equations to students who have no means of relating the concepts to the physical world need to be improved. Instilling a keen interest in science and mathematics may be a way to help STEM students endure the inherent challenges involved in their majors. The present work is an account of a focused effort to plant a seed of interest in science and mathematics in incoming freshman students at Cal State LA. Armed with the belief that students will become genuinely interested in science and mathematics if they are presented in an interesting way, a group of faculty members from various engineering disciplines at Cal State LA and Cal Poly SLO have started a Calculus and Physics workshop called Mathemagics for the incoming freshman engineering students. The activities aim to spark an interest in science and mathematics in incoming freshmen students hoping that the connections they make between mathematical theory and physical reality as well as increased motivation will translate into success in STEM during their following academic endeavors.

1. Introduction

Despite many efforts by the US government, non-profit organizations, and academic establishments, the attrition rate remains alarmingly high at of institutes of higher education that serve predominantly economically deprived areas. One of those institutions is California State University, Los Angeles (CSULA) which is located at the eastern edge of Los Angeles, an economically disadvantaged area. According to CSULA's Institutional Research, only 6.3% of its students graduated with a BS degree in 4 years and only 41.1% of its students were able to graduate in 6 years [1]. Nationwide, in the US about 59% of students graduate in 6 years [2]. Average US college student spends at least 2 years more on her/his B.S. degree than the degree was meant to require. STEM degrees take even longer. The National Bureau of Economic Research indicates a correlation between the lack of resources—both on the part of students and the institutions—and prolonged graduation times [3].

The first year in college can be intimidating for any student, but especially for students in rigorous engineering majors. To exacerbate that situation, students entering engineering majors at CSULA are typically underprepared in math and science: less than 5% place into Calculus I upon admission. A group of STEM faculty at CSULA has been working on improving education for engineering students for several years [4-6]. A new program at CSULA, the First Year Experience in the College of Engineering, Computer Science, and Technology (FYrE@ECST) has been created to lay a stronger foundation in calculus and physics for the freshmen engineering and technology majors at CSULA. One of the aims of FYrE is to engage freshman students in the learning process to encourage their interest in science and math. Toward this end, Mathemagics was developed with the intention of showing students the magical ways mathematics describes the physical world. One of the aims of Mathemagics is to instill a genuine love of science and math in students by studying simple mathematical relationships that describe physical phenomena familiar to students. Mathemagics is based on a proven fact that teaching mathematics in a way that it relates to students' everyday lives results in a better learning outcome than following the traditional lecture/practice method [7]. If successful, the students—empowered by the drive to understand the physics of the universe—are expected to take an active role in their own learning process and work hard to overcome many challenges inherent to earning an engineering degree.

Both the students and the instructors need to undergo a change in mindset. They both need to abandon emphasis on exam grades over gaining knowledge [8]. The student should be trained to abandon studying for exams, a remnant of No Child Left Behind policy. The instructors should realize that it is unreasonable to expect training the future scientists if earning a high score on an exam is given a higher priority than in depth learning. Without a doubt, no one achieves greatness in any discipline that one dislikes. We spend countless hours and overcome immense obstacles learning about what we love because spending time on what we love never becomes a tedious chore; we call it a “hobby” instead of a chore. One important goal of Mathemagics is to change the task of studying math and science into a hobby of learning by introducing the joy of learning to students. To accomplish the task, a series of experiments were designed as described below.

2. Discussion of Experiments

Out of the 150 freshman ECST majors who passed out of Pre-Calculus and were eligible to take Calculus I by their first term of college in Fall 2015, 33 students were selected randomly to be part of the pilot FYrE@ECST cohort; these students were divided into two classes to ensure proper management of all activities. Mathemagics activities were inserted into Introduction to Higher Education course in the form of 5 workshops each 100 minutes in duration. Each workshop started with a presentation by one of the faculty members involved. The presentations started with some interesting facts about the physical world, depending on the activity, and tied into the subject matter of the day. The first part was meant to whet the students’ appetite as they learned about the universe and the second part was to unravel a mystery of the universe through some simple activities. Those activities are described here briefly.

2.1. Constant of Acceleration Due to Gravity Calculated from Free Falling Ball

In the first experiment, students were asked to determine the acceleration due to gravity by dropping a tennis ball in front of a measuring tape and plotting the position of the ball vs. time. Students were asked to install a free app on their cell phones that allowed them to capture the free fall of the tennis ball as a video, which could be viewed in slow motion to record position of the ball vs. time. Prior to conducting the experiment, a discussion was conducted to come up with an equation that would describe the ball’s position as a function of time: $y = \frac{1}{2} g t^2$ Students were instructed to make a plot of position vs. time for the ball similar to the one shown in Fig.1a. Finally, the students were instructed to determine velocity from rate of change of position vs. time at various intervals and finally by plotting velocity vs. time, determine the rate of change of velocity, as shown in Fig. 1b. Students were to determine g from the slope of the straight line fit to the data points in Fig. 1b. Regretfully, this experiment proved to be too much for our students and only one student was able to calculate a value that was close to 9.81 m/s^2. As a result, we decided to ease on “discovery” part of the activities and concentrated more on “guided discovery” as reflected in the rest of the activities.

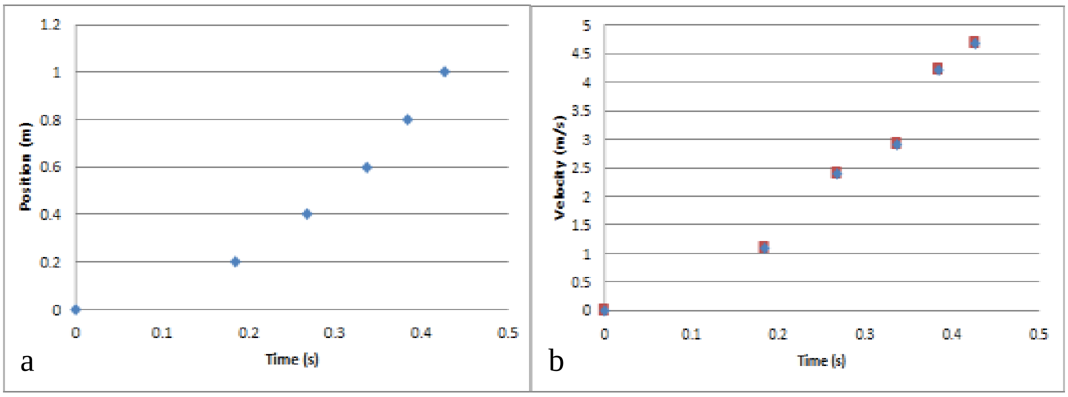

Fig. 1a&b. Plot of drop time vs. distance traveled for a ball undergoing free fall.

2.2. Cartesian Components of Velocity of a Projectile

Two tracks were devised on top of one another as shown in Fig. 2. Students were engaged in a discussion about vector components of velocity in general then were asked to predict the distance between the two balls when the upper ball is at the same height as the lower ball. After discussing all possibilities within their groups of 4 students, they were asked to decide on the position of the upper ball with respect to the lower ball and justify their answer with reasoning. After coming up with a decision, they had to release the two steel balls simultaneously on their tracks and observe if their prediction was correct. Finally, they had to come up with an explanation of distance, or lack thereof, between the balls. This activity resulted in the liveliest interaction among the students.

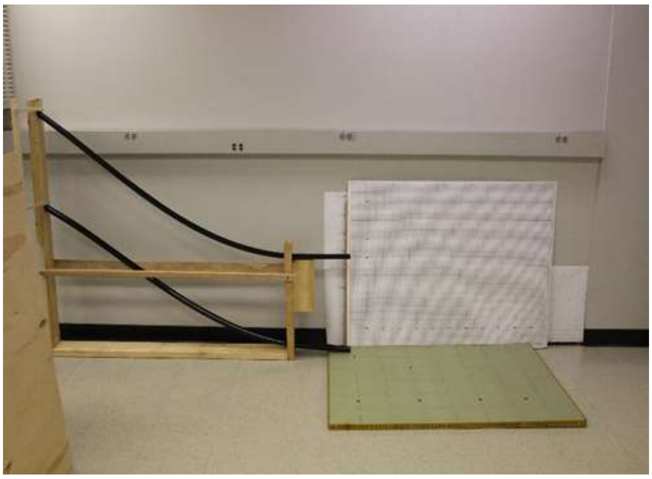

Fig. 2. Demonstration of horizontal motion of two projectiles released from different heights.

2.3. Constant of Acceleration Due to Gravity Calculated from Oscillations of a Pendulum

A presentation on periods of oscillation of various systems in the universe was delivered to help students recognize naturally occurring frequencies built into systems all around us, from the period of the earth's revolution around the sun all the way down to the period of oscillation of a water molecule. They were also introduced to Foucault's Pendulum and how they may prove rotation of the earth. Once the students' curiosity was piqued, they were shown a simple pendulum prepared by the instructors, followed by the explanation that the period of oscillation of a pendulum is proportional to the square root of its length through: $T = 2\pi\sqrt{\frac{l}{g}}$. Therefore, one may calculate *g* from $g = \frac{l}{(2\pi T)^2}$ knowing the period of oscillation *T* and the length *l* of the pendulum. Students were asked to determine *g* and compare it to its approximate value in Los Angeles of 9.796 m/s^2.

2.4. Estimation of the Height of a Building Using Similar Triangles

This activity started by discussing similar triangles with the students and how the ratios of edges of two similar triangles are constants. Then the students were provided with 12-inch diameter round mirrors and a yardstick, and were asked to determine the height of CSULA library building. Some possible approaches, using similar triangles, are illustrated in Fig. 3, none of which were at any point presented to the students. The students were asked to devise their own plan and measurements. This resulted in a good level of inquiry on the students' part. After the students returned with their estimated heights, they discussed the relevance and applicability of similar triangles to this task.

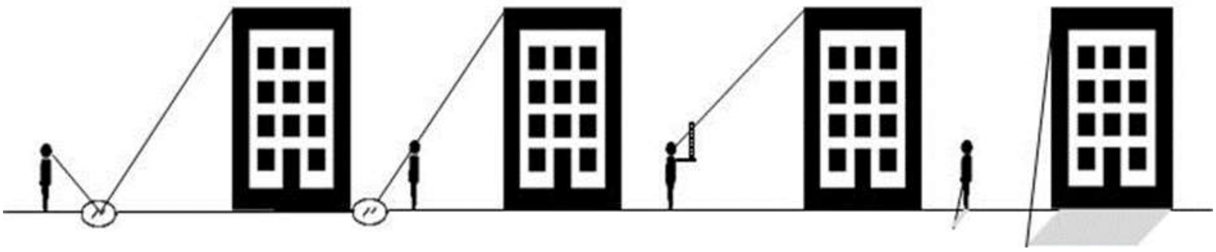

Fig. 3. Four methods for estimating the height of a building using similar triangles.

2.5. Archimedes Method for Calculating Density of an Object

As a way of getting the students' attention and getting them to form a better mental picture of buoyancy, the instructor for this workshop told the Archimedes' story, the tale of the cheating goldsmith, and showed a depiction of Archimedes running naked on the streets shouting eureka. Students were then led in a discussion on determining density of an object using Archimedes principle. Starting from the definition of density, students were shown how they may arrive at the equation for calculating the density of an immersed object:

$$\rho_{Immersed\ Object} = \frac{M_{Dry}}{M_{Dry} - M_{Immersed}}$$

Finally, they were given a piece of brass and three different set ups for estimating the density of the brass and the fraction of weight comprised of zinc in the alloy.

3. Results and Conclusions

The assessment, which included surveys and focus groups, conducted after completion of the Mathemagics workshops by an independent consultant, indicated that students generally felt going through Mathemagics was a positive experience. They believed it would help them in their future academic endeavors. The pilot program described here was a short experiment with moderate positive results. By institutionalizing as a 1st-semester 1-unit workshop for credit, with 15 sessions instead of 5, we hope to encourage engineering students to have a more positive outlook on mathematics and physics from start of their program. In addition to the benefits for the students, we as faculty, also benefitted. We enjoyed developing the activities and because we love engineering, we found we spent many hours debating how to maximize the benefits of each session; as a result we learned together. This developed a very good collaborative team of faculty from two universities. We also learned that sometimes less is more when designing the activities. We often felt we ran out of time (with the 100-minute allotted time) and found ourselves rushing to complete a portion of what we had prepared.

4. Acknowledgements

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