2018 ASEE Mid-Atlantic Section Spring Conference: Washington, District of Columbia Apr 6

Developing an engineering mindset: teacher enrichment strategies employing project-based learning in optics and cosmic ray study

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Developing an engineering mindset: teacher enrichment strategies employing project-based learning in optics and cosmic ray study

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Abstract

The three principles of K-12 engineering education, namely, design, science knowledge, and mindset development have been implemented in a program designed for teacher enrichment using optics and cosmic ray projects. The design guideline of using disposable products was imposed such that the designs can be translated effectively from a community college setting with technician support to a high school standalone setting. The transformation principle of a physics question to a design driven question was illustrated with examples from mechanics as a foundation for paradigm shift, and then extended to optics and particle counting. The physics principles were clarified with the various iterated designs for complying with additional constraints. A research component in solar monitoring and physics using cosmic ray public data was also implemented to further the teacher enrichment with deployable algorithms for high school setting equipped with Microsoft Excel. An assessment rubric based on design deliverables is discussed.

Keywords

Design driven physics questions, iterated designs with constraints, muon and neutron flux volatility, solar eruption Sep-6-2017, Solar Dynamics Observatory high school projects

Introduction

The three principles of K-12 engineering education, namely, design, science knowledge, and mindset development, explained by Linda Katehi (Chancellor of the University of California Davis and Chair of the Committee on K-12 Engineering Education in the National Academy of Engineering and National Research Council Center for Education) on her report to Congress[1], have been implemented in a program designed for teacher enrichment using optics and cosmic ray projects. A teacher usually has a tight lesson plan calibrated to the requirement of a State Education Board and/or SAT/ACT requirement nationwide. The challenge of asking a teacher to train a student's mind for the development of an engineering mindset is not an easy task. Among the high school subjects, physics could be one of the subject that is amenable for modification in terms of exposing students to design related to science knowledge. Given that physics is a required subject for most engineering programs in college, the implementation of using high school physics lessons to train high school students in the learning of design must start with a paradigm shift in teachers themselves. When a teacher had the training in the transformation of a regular physics text question to a design question, the subsequent transfer of that design knowledge to a high school lesson would be achievable, not to mention when a teacher has been enriched with project-based applied research experience that could be translated from a college setting onto a high school setting.

General Design Training

The transformation of a regular physics problem to a design question can be done using the regular textbook physics problems. The use of calculus facilitates the transformation such that the rate of change indicated by a trend on a graph could induce a design question with respect to a change. Examples include velocity versus reachable height, safety angle for leaning a ladder, static friction supporting pure rolling, kinetic friction versus ramp angle, etc. The first design could be an answer to a using the trend in a simplified model while iterated designs would correspond to refined modeling with an addition constraint. This method would be implementable for high school teacher engineering mindset development when delivered as an enrichment program in a college setting.

Teachers using the design questioning approach in a high school setting would develop his/her design mindset readily when compared to problems provided in a traditional textbook. For example, take the basketball throwing example in Chapter 3 of Coletta (Physics Fundamentals Physics Curriculum & Instruction; 2nd edition 2010)) and ask how to launch a food package onto a third floor balcony in a street flooding situation. A displayed trend on a graph of location versus angle or speed would demonstrate an understanding of the projectile motion knowledge. A subsequent imposition of a constraint on the food delivery boat such as oscillatory water level would require an iterated design with some appropriate assumptions. Another example would be the L-shape arm bio-mechanical model where a string was used to connect the vertical piece to the horizontal piece for the simulation of forearm motion. A subsequent movable upper arm would necessitate iterated designs with an additional string, two strings for pivoting with elbow and shoulder joints. Another "design with iteration" method would be the breaking down of a medium difficulty problem needing two equations in a textbook into a simpler problem and a related design, followed by an addition constraint with an iterated design to recover the full content in the utilization of the second equation. For example, a block can be used to embed a speedy bullet and the block displacement can be used to gauge the bullet speed. A subsequent addition of a string/spring to the block would be an oscillatory design such that the block would not need to be fetched after stopping the bullet.

Project-based learning is a holistic approach for the development of innovation in an engineering mindset. Project-based learning solves each individual problem when it arises. Examples in foundational mechanics, optics, and particle counting that are deployable in a high school setting by a teacher are presented in this article for illustration.

Using disposable products such as rubbing alcohol and brines with different densities inside fluid columns for object dropping investigation based on folk physics or common sense has been popular. An advanced investigation on fluid boundary flow effect can also be explored as a project. A #2 rubber stopper drilled with 2 holes would take about 4 sec to fall/sink in a 15-cm water column provided by a Kimble Kimar Class-A 50 mL graduated cylinder when compared to a solid stopper taking 6 sec. Tension projects can be done using 3-panel project display boards with good support. Three push pins or thumb tacks can be used as anchors to stretch out a rubber band. An additional weight would provide further elongation for the learning of forces in equilibrium. The Stanford University Solar Research Center rubber band demonstration of magnetic reconnection using rubber band can also be done as well. A leaning ballpoint pen Bic would mimic a ladder safety angle equilibrium problem in a textbook and the coefficient of static friction be explored. Using the practical rule that the vertical contact force, horizontal contact force and non-contact weight must meet at a single point upon spatial extrapolation, the force equilibrium triangle can be used to calculate the safety angle. A leaning ruler with small holes can accept a weight attachment to mimic the case of a person standing on a ladder. A 30-cm Fiskars ruler with a narrow center groove when elevated would support a sliding of an AA battery down the ruler incline. A small tapping to start the sliding would produce a constant speed condition such that the kinetic friction is balanced by the weight component along the incline direction. A larger incline angle would produce sliding acceleration such that the static fiction can be explored together with the gravity effect. A collision with another AA battery positioned at the end of the ruler incline would mimic collision examples. All of these motions would be recordable as cell phone videos and the ImageJ free software can be used to analyze the data. The first design has a physics explanation and subsequent modification to the first design would provide iteration opportunity to develop an engineering mindset.

Optics can be studied with a divergent Keychain LED source. The LED distance to an object for a clear shadow in transmission can be measured and an insertion of a magnifying glass would change that distance. Two pairs of eyeglasses can be used to form a low power telescope for demonstration. A concave beauty mirror as light collecting element can also be used for telescope demonstration. The ABCD matrix linear algebra method can be used to keep track of the light propagation through the optical elements. Insertion of an optical element in a new design would have a computation equivalent of adding an extra matrix, just like the splitting of an object into two objects would have a computation equivalent of applying the Newton's Second Law on two massless-string connected objects under the influence of an external force. Teachers who know that the string internal force magnitude T is independent of sliding friction and $dT/d\theta = 0$ when θ represents the incline slope would have an expectation that the ABCD optical matrix computation could reveal invariant parameters in certain designs. A laser pointer, which is more expensive and not a disposable item, can be used to demonstrate interference and diffraction as well. Aperture induced classical diffraction features seen on Hubble Space Telescope images can also be analyzed. Citizen Scientists' Youtube data on subauroral ion drift (SAID) with purple auroras would also be of interested[2]. Modern physics topics such as the purpose of particle counting experiment can be demonstrated with a loaf of bread when the loaf was cut up as one-half, one-quarter, one-eight, etc. These examples would introduce designs into a physics class and a trained teacher could add a design component into a high school setting.

Project-based Applied Research

An applied research project in the understanding of solar physics using cosmic ray and spacecraft public data has been implemented to further the teacher enrichment with deployable algorithms for high school setting equipped with Microsoft Excel. Earth has been bombarded by cosmic ray particles. Solar eruption events, indicated by the SDO spacecraft, are known to sweep away the incoming galactic cosmic ray particles[3]. The primary cosmic ray product is muon production in the atmosphere while neutron production is a secondary effect. Cosmic ray monitoring stations usually operate with the measurements of muon and/or neutron flux data. The solar particle magnetic fluctuation could be measured by the ACE spacecraft and the concept of magnetic cloud has been used to study the structural details[4].

An example of a solar eruption investigation with muon/neutron flux and spacecraft data in the public domain is presented for interested teachers. The reported 6 Sep 2017 double solar eruptions within a 3-hr duration and a later eruption on 10 Sep 2017 from AR 2673 moving across the solar disk had been analyzed[5]. The 10 Sep 2017 eruption was on the Sun's western limb with a magnetic field spiral pattern pointing back onto Earth[6]. A Ground Level Event (GLE) surge were observed in the South Pole Neutron Monitor[7], and GLE event analysis during solar cycle decreasing cycle has been published[8]. The solar proton energy arrival times were measured by the GOES spacecraft as well[9]. The muon flux data at 0 m.w.e. (from Yakutsk Station[10]) is shown in Figure 1 with suppression feature.

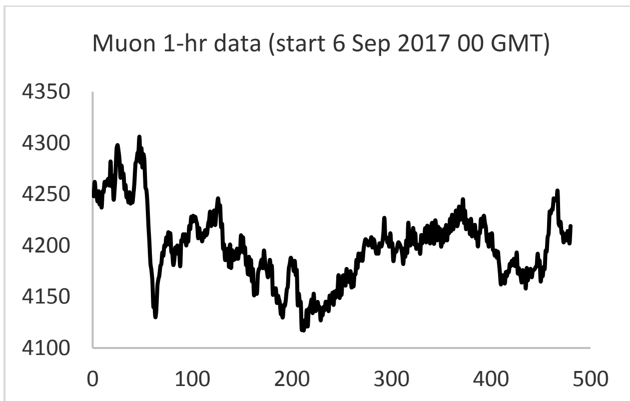

Figure 1: The muon 1-hr flux data from 6 Sep 2017 00-GMT to 17 Sep 2017 23-GMT (N = 480). The first signal suppression occurred at (63, 4130) which corresponds to 8 Sep 2017 14:00 GMT

The neutron flux data (from Neutron Monitoring Stations[11]) are shown in Figure 2

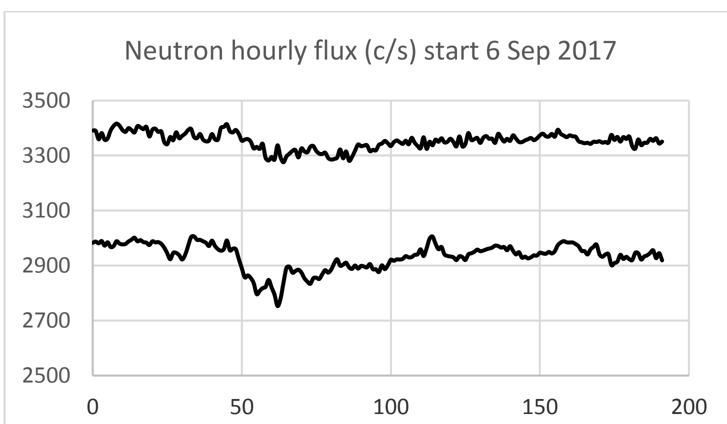

Figure 2: The neutron 1-hr flux data (Counts/sec) with the same time duration of Figure 1. The Athens Center neutron data (upper curve) was multiplied by 2 for easy display with the Newark Center neutron data (lower curve).

The Newark Center neutron flux data (lower curve) showed multiple suppression features. The Athens Center neutron data (upper curve) showed less distinctive suppression features, consistent with ionosphere response having strong disturbance in North and South Americas. The spacewather.com web page discussed the major related shortwave radio blackout and also showed the ionosphere response having a strong disturbance in North America and South America that disrupted GPS signal (1 dB absorption at 35 MHz for North America and South America)[12]. The high latitude proton recovery time was about 41 hours as indicated in a subsequent ionosphere map posted 3 hours later[13]. The time delay of the first suppression feature in Figure 1 relative to the GOES X-ray signal time could be used to calculate the average speed value using a distance of 1 AU[14].

Discussion

The project-based learning exercises can be delivered online to interested teachers. Some of the data videos can be downloaded from our website when the paper is published[15]. The project-based applied research in solar physics with cosmic ray monitoring muon/neutron data can also be delivered online and NASA has scientists that would answer questions through online Q&A sessions. The Solar Dynamics Observatory has an outreach program for literacy at the elementary school level[16]. The solar physics related cosmic ray project focuses on the enrichment of high school teachers with continuous new data. Currently Fermi Lab is supporting a 3-week teacher summer program in cosmic ray detection and our Queensborough Community College (QCC) has been one of the active participating institutions[17]. Our assessment data showed that an interested teacher would bring his/her enrichment experience back to high school to help students to do project based learning and problem solving. The use of Excel at the high school level for the volatility study of neutron flux generated by cosmic ray had been reported by us earlier[18], and the Excel method is also applicable for studying muon data volatility. Innovation is about problem solving and is not about ideas, said Harvard Business Review[19]. The functionality of STEM in a society can be illustrated effectively as technology driven by engineering designs using science knowledge based on the clarity of mathematics. A teacher empowerment in terms of design enabling activities would be achievable with an assumption that an instructor teaches a portion of what he/she knows. The broadening of horizon is important for a teacher to develop design related inquiry questions. Data computation questions from correlation in statistics to AI decision algorithm and timing questions in the Photo Multiplier Tube within the cosmic ray project would enrich an engaged teacher to be ready for a paradigm shift from the regular professional development activity currently offered in some school districts to an engineering design-specific experience[20]. The Google Exoplanet AI codes, with Python and Tensor-Flow, was released to the public on Github recently[21-22], and cosmic ray public data analysis examining relationships with solar eruptions would benefit from a similar AI approach. Some materials developed for teacher enrichment have been used for a College Now course, where high school students take a research course in QCC. If the College Board moves toward a SAT II exam in engineering and/or engineering physics with focuses on iterative design questions, high school students will be more prepared to pursuit engineering programs in college.

An assessment rubric example for the development of an engineering mindset, applicable for teachers to use in AP Physics classes, is shown in Table 1. The initial design was to find the initial parameters to deliver food to a specific location. A first design can be assessed with the correctness of the graph of location versus angle or speed. A subsequent imposition of a constraint on the food delivery boat such as oscillatory water level could favor a rotatable launch tube with a constant launch speed, when steady energy usage is a practical engineering concern.

Table 1: An experiential learning assessment rubric.

Deliverable	Highly Competent	Competent	Needs improvement
Design for variable angle values 20%	Projectle location vesus angle graph done correctly	Made one mistake	Made two or more mistakes
Design for variable speed values 20%	Projectile location versus speed graph done correctly	Make one mistake	Made two or more mistakes
Design with a rotatable launch tube for oscillatory water level 20%	Showing a family of graphs (3 at least) for up, neutral, and down water levels	Showing 2 graphs for up and down water levels	Showing one graph for up or down water level
Design with a variable speed launch tube for oscillatory water level 20%	Showing a family of graphs (3 at least) for up, neutral, and down water levels	Showing 2 graphs for up and down water levels	Showing one graph for up or down water level
Energy comparison 20%	Correct energy contrast between fixed speed design and fixed angle design; for up, neutral and down water levels	Made one mistake	Made two or more mistakes

Conclusions

The three principles of K-12 engineering education, namely, design, science knowledge, and mindset development have been implemented in a program designed for teacher enrichment. The paradigm shift from a physics textbook question to a design question in the delivery of learning materials would offer a firm foundation for a teacher to help high school students to receive an introduction to engineering education. Future studies could include an investigation of the effectiveness of the integration of project-based learning and applied research into Teacher Professional Development Programs, the development of a SAT II high school exam on engineering, etc.

Acknowledgments

The authors thank Alexei Kisselev for demonstration support and the Muon and Neutron Monitoring Stations for sharing their data in the Public Domain.

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