AC 2010-1077: USING A MOUSETRAP-POWERED VEHICLE DESIGN ACTIVITY TO CONVEY ENGINEERING CONCEPTS

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Using a Mousetrap-Powered Vehicle Design Activity to Convey Engineering Concepts

Abstract

As part of a NSF-sponsored project within GK-12, a curricular unit was introduced to students in an urban middle school elective course. The module sought to immerse students in a design project, during which they would be introduced to theories and concepts relevant to the construction of a mousetrap-powered vehicle.

The unit was designed to fit within the timeframe of the middle school's elective period, a 1.5-hour session per week for 10 weeks. After introducing the course goals and demonstrating the end "product," students were encouraged to build upon a basic design specified in a guide during a two-week building phase, using standard hardware and "everyday" materials. Each week thereafter, lessons on measurement, unit conversion, forces, torque, and energy were introduced and corresponding activities were adapted to the mousetrap vehicle project. Vehicle-specific investigations on friction (forces) and moment of inertia (torque) allowed students to calculate the efficiency of their mousetrap-powered car and determine which modifications were necessary to achieve their goal.

At the completion of the elective, students responded to an open-ended survey that gauged their interest in the project, impression of science and mathematics, and willingness to pursue similar "hands-on" projects. Survey results suggest that students gained a better understanding of the physical concepts taught in lessons as they experimented with their own mousetrap-powered vehicle models, and might be more willing to approach other scientific concepts if taught by example.

Introduction

Over the course of the 2008-2009 academic year, an elective course was developed and implemented at Middle Years Alternative (MYA), an urban middle school in Philadelphia, PA, as part of the National Science Foundation (NSF) Graduate K-12 Fellowship Program (GK-12). In accordance with the GK-12 outreach goals – enriching the content of courses related to science, technology, engineering, and mathematics (STEM) – the "module" of lessons and activities was also created in part to increase students' knowledge of everyday physical phenomena and awareness of the engineering discipline.

Inquiry and design-based activities have been promoted in the National Research Council's National Science Education Standards (NSES), and have garnered favorable support in the middle and high school settings [1-4]. While pure discovery methods of inquiry for learning such as constructivism have been met with criticism [5-6], inquiry-based activities that provide sufficient support, or scaffolding, afford students an opportunity to explore topics that would otherwise be too complex for their abilities [7-8]. As multiple science topics may be supported by a single engineering lesson, the National Research Council frames 'design as the technological parallel to inquiry in science' in the NSES [9]. A design activity may also introduce the creation of an artifact by the students, which may serve as the object of the students' application of scientific principles and concepts [2], as well as a tangible and accessible representation of knowledge that frees up mental resources as students develop complex ideas [1].

Additional ideas set forth in the NSES promote the ability of students to learn to tell the difference between science and technology, to compare and evaluate designed artifacts, to understand how things work, and to do "technological design" [9]. The elective course sought to cover these tasks in a "module" of lessons and activities in which students deconstruct the physical concepts involved in the motion of a vehicle (the physical artifact) and apply these concepts in the redesign of the vehicle. Worksheets accompanied the activities and provided instruction (procedures and heuristics) similar to the 'Design Sheet' that had been suggested to improve students' learning capability in learning by design (LBD) environments [2-3,8,10]. Students also used worksheets that provided guidance for the technological tools (sensors) used in the experimental activities. Learning studies had been conducted on sets of students exploring the physical concepts of thermodynamics[8] and collisions[11] through computer-based simulations, which are also considered technological learning tools. However, the investigators of these studies seem to have been split on the influence of "pure discovery" inquiry learning. Though neither study could conclude that students' learning was significantly different as a result of different scaffolding approaches, Vreman-de Olde et al. (2006) suggested that scaffolding methods engaged students in the activity, while Swaak et al. (2004) posited that scaffolding discouraged students from exploring the simulation outside the prompts.

In each of the course iterations, the amount of scaffolding was increased based on students' progress. In the first iteration, students were given objectives and minimal guidance was given to students until the related physics topics were introduced. In the second iteration, a building guide was provided to students at the start of the course and guidance was included for the "measurement" and "conversion" topics. After these initial topics, the physical concepts of force and torque, which can be directly approximated using sensors, were explored using a mousetrap-powered vehicle. In the first and second course iterations, technology was used in the form of force and motion sensors that interfaced with PASCO Explorer units. The Explorer graphically displayed the data and students were instructed to observe and record parts of the data in a worksheet-based approach. For the third course iteration, a less-extensive worksheet was provided, as calculations, textual instructions, and multimedia examples were embedded into the PASCO® DataStudio software program. The software interface could be directly configured with the sensors and allowed a customizable data display so that students' learning was appropriately focused on the problem domain [12].

In contrast to the aforementioned middle school LBD studies[2-4], the module was used as part of an elective course in an urban middle school during a period students considered "exploratory" or "free" due to its ungraded nature, and not all students present in a given term had necessarily volunteered to be involved. Thus, there was a continual challenge to maintain students' interest while persuading them to reason throughout the activities. Learning by design environments advocate an authentic context to effectively motivate students toward completing the design task. Improving the design of a mousetrap-powered vehicle incorporates physical concepts that apply not only to engineering but also to an understanding of the need for innovation, as embodied in competitions such as Extreme Gravity Racing and the X Prize.

As a project developed within the context of GK-12, the goal of the mousetrap-powered vehicle design module is to not only improve students' science literacy, but also create an awareness of the engineering discipline and importance of advanced math and science courses. The design learning method, which involved constructing an artifact and using it to explore physical concepts, had been refined for the particular student audience and environment and appropriate scaffolding was created to encourage learning independence among the students. Anecdotal observations, along with survey results of students that actively participated, indicate that a highly scaffolded learning environment is necessary to persuade involvement, maintain engagement, and foster awareness and interest in engineering careers among middle school students in the urban setting in which this module was implemented.

Methods

The module was implemented in a 1.5-hr long elective period held at the end of each academic week at MYA, over the course of 8 weeks that corresponded with each academic trimester. The students involved ranged from 6^{th}-8^{th} grade levels, low to mid-SES, with ages ranging between 12-14 years. A topic was briefly introduced each period via a Powerpoint presentation, and the remaining time was allotted for the students to complete a related activity. After each student group had constructed their mousetrap-powered vehicle, they could complete topics on measurement, unit conversion, forces, torque, and energy using the artifact.

The guidance offered during the progression of the school year was revised according to students' achievement. Lessons and activities on measurement and conversion topics were loosely structured during the first trimester, as they were on par with curriculum for 6^{th}-8^{th} grade students. For the first two trimesters, the physics topics were scaffolded using a paper-and-pencil worksheet that enumerated and explained the relation of each mathematical equation used to its associated physical concept. This was expected to aid the transparency of the problemsolving process reducing the cognitive workload to "plug-and-chug" problems intended for students that had not yet taken Algebra. During the second trimester, additional support was built-in for the construction, measurement, and conversion activities that were not previously guided. In the third trimester, the paper-and-pencil worksheets were converted to computer-based activities.

An overview of this curricular unit's lessons and activities, and supporting materials may be found here:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_0_overview.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_456_activity_worksheets.zip
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_456_activity_worksheets_paper.zip

Brief explanations of each activity and applicable lessons follow below.

"Construct a Car" Activity

The students begin the module by constructing a mousetrap-powered car. A selection of building materials was provided: compact discs, 1/2" wood dowels (with 13/64" holes bored in each end), large craft sticks (with 1/4" holes drilled in each end), 1/2" inner diameter rubber grommets, fully threaded 1/4" x 3" hex head bolts, 1/4" lock washers, 1/4" star washers, 1/4" finish nuts, 1/4" fender washers, 1/4" washers, 1/4" wood screws, 1/2" Eyebolts, GOOP® adhesive, wire twist ties, Victor® brand mousetraps, and duct tape. As these materials could be re-used, the same materials were available in all course iterations. As mentioned above, a step-by-step construction guide was created to "seed" the students with ideas in the second and third course iterations.

"Construct a Car" activity and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_1_activity_construct_a_car.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_1_activity_construct_a_car_plans.pdf

"Quantify It" Lesson and Activity

The background of SI and Imperial units was presented to the students to refresh their measurement skills, which was reinforced with a brief activity involving measurement of the dimensions of classroom objects (whiteboard, desks, calculators) and their own mousetrap car wheels and axles. These measurements would be used in subsequent activities.

"Quantify It" lesson, activity, and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_2_lesson_quantify_it.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_2_lesson_quantify_it.ppt
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_2_activity_quantify_it.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_2_activity_quantify_it_worksheet.pdf

"Convert It" Lesson and Activity

The idea of unit equivalence, and concept of unit conversion using this principle, was presented to the students. Each student was then responsible for converting the measurements taken in the "Quantify It" activity. The converted measurements (Imperial→SI) would be used in the next activities.

"Convert It" lesson, activity, and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_3_lesson_convert_it.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_3_lesson_convert_it.ppt
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_3_activity_convert_it.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_3_activity_convert_it_worksheet.pdf

"Forces, Forces, Everywhere" Lesson and "Dragged Racers" Activity

The concepts of acceleration and force were presented in the context of Newton's 2nd Law of Motion. The "Dragged Racers" activity illustrated the concept of frictional forces, as students could compare the amount of force necessary to move their car with the wheels rolling (static friction) or sliding (kinetic friction) on the floor. The forces measured by the students are used in the design objective of the "Max Your Ride" activity.

"Forces, Forces, Everywhere" lesson, "Dragged Racers" activity, and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_4_lesson_forces_forces_everywhere.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_4_lesson_forces_forces_everywhere.ppt
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_4_activity_dragged_racers.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_4_activity_dragged_racers_worksheet.pdf

"Torqued" Lesson and "Spinners" Activity

The idea of rotational motion was contrasted to rectilinear motion using the concept of a circle (and circumference), after which the idea of angular quantities of position, velocity, and acceleration were compared to their corresponding linear quantities, leading up to an explanation of torque as a rotational force. Students then measured the linear acceleration of a weight wound around the axle as it dropped. By converting the average linear acceleration to angular acceleration, students could compute the average moment of inertia of a rear axle-and-wheel assembly. These quantities are used in the "Max Your Ride" activity.

"Torqued" lesson, "Spinners" activity, and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_lesson_torqued.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_lesson_torqued.ppt
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_activity_spinners.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_activity_spinners_worksheet.pdf

2.6. "Energetically Challenged" Lesson and "Max Your Ride" Activity

As the summative lesson and activity set in the module, the goal of the lesson is to build upon the students' idea of energy (calorie and metabolism) and relate it to the mechanical energy that is input (spring force from mousetrap arm) and transferred (string-to-axle), resulting in the drive axle rotating without slipping. Students could evaluate the mechanical efficiency of their vehicle and re-evaluate their design strategy based on the outcomes of "Dragged Racers" and "Spinners" experiments.

"Energetically Challenged" lesson, "Max Your Ride" activity, and supporting materials available for download at:
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_lesson_energetically_challenged.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_5_lesson_energetically_challenged.ppt
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_6_activity_max_your_ride.pdf
http://gk12.coe.drexel.edu/modules/doc/John_Fitzpatrick%5Cchedda_6_activity_max_your_ride_worksheet.pdf

Results

Results varied by term, as each section progressed further through the module with additional guidance. Anecdotal observations and survey submissions from the third term were used to evaluate the effectiveness of the module in its final state.

Anecdotal Observations, Term 1

Students were encouraged to build a mousetrap-powered vehicle based on pictures and videos that had been shown in a presentation explaining the goals and procedures of the elective course. The supplied parts and hardware were contained in bins accessible to all students. All of the students had difficulty visualizing how to assemble the parts and/or using the supplied tools (wrenches, screwdrivers, etc.), so the building timeframe took longer than anticipated. By the fifth week, all students had completed their vehicles and were ready for the lesson and activity dealing with forces, which was an initial step for determining how to manipulate the vehicle in order for it to roll without slipping. Unfortunately, at this point the students were somewhat frustrated with the slow progression of the elective and lost interest in the project when their cars failed to work immediately, even though their design had to be modified.

Anecdotal Observations, Term 2

All students followed the step-by-step construction guide introduced in the second iteration of the module. A basic car could be quickly assembled using craft sticks, fully and partially threaded bolts, washers, nuts, and a mousetrap. However, the car would need modification in order to roll, and this basic design was intended to provide a starting point for lessons focused on improving the vehicle (i.e. improve a failed design). Students completed the construction activity within two weeks and began the engineering activities using the force and motion sensors for data collection. Initially, the students were excited to use the PASCO® Explorer (handheld) units, but the excitement faded after many students had difficulty using the interface, navigating to wrong screens and changing the graphed variables. The Explorer is a sophisticated tool, but was complicated for many students to use immediately without training. Though additional, step-by-step slides were presented to the students to briefly provide a "training session" and the forces activity ("Dragged Racers") was re-tooled twice, only several students were still interested in performing the experiments. Even though students didn't stick through the experiments, many enjoyed the feedback response of real-time data and played "guessing games" with the data output given an input. This was a true inroad for teachable moments, as I explained why the graph looked like it did when I made the rounds to each group experimenting with the Explorer units.

Anecdotal Observations, Term 3

Students built the basic model, but used an alternative construction method compared to the second term, substituting compact disks for fender washers as the rear wheels. This partially solved the issue of the rear wheels slipping and the vehicle "spinning out," which allowed the students to modify their cars without entirely rebuilding them. Students seemed to be encouraged to try the experiments and work more independently with the software interface than with the handheld Explorer unit. Though all the students observed the physical interactions highlighted in the experiments, they preferred to modify their vehicles by trial-and-error until their vehicles rolled without slipping.

Media

Video and pictures of students in the final course iteration show certain students testing and making modifications to their vehicle in order to achieve the "roll without slipping" condition. Students are pictured attaching duct tape to car wheels and extending the mousetrap arm length with bamboo chopsticks. Lacking a formally graded curriculum, these depictions of students completing the design objectives may serve as an authentic assessment[13-14] of their learning during the course, albeit at a level appropriate for the environment and grade level of the students involved.

Exit Survey

An exit survey (questions displayed in Table 1) was given to students involved in the final term of the module, since the students in the previous sections did not complete the core activities intended as the educational portion of the module. Of the 14 students in the final trimester, surveys were considered from 12 students who participated in the project and completed the activities.

The intent of the qualitative survey was to capture the knowledge, attitude, and skills of the students as they reflected on their experience in the elective. Of the seven questions, five were posed to allow a Yes/No objective response while allowing students to explain themselves. An additional two reflection questions were open ended. The exit survey responses are shown in Table 1.

Table 1: Exit survey responses from twelve active course participants.

Question	"Yes" Responses	"No" Responses	Noteworthy Responses
Are you glad you chose this ___ ____ course? If not, which course would you have taken if given the option again?	10	2	• I had fun and the activities were exciting • I am glad I chose this course because we got to build things • Yes, because we learn how to create mousetrap cars
Do you like building things? Have you built things before this elective?	10	2	• Yes, and a boat last year. • Yes, I built my bed • Yes, I find it challenging • Yes, because my dad was a griess [sic] monkey • Yes, I have build [sic] a plane
Would you be more interested in science and math if they were taught using a model like the mousetrap car?	11	1	• Yes because it would be more interesting • Yes. It give you a better look • Yes…it makes things more interesting and fun.
If you could find plans for other projects like the mousetrap-powered car on the internet, would you try to build them at home?	11	1	• I would try to build it if it is not very complicated and if I have the right materials to make it • I would probably try something new • Yes I would because I love to do this
The process of building and refining a model (like the mousetrap car) using mathematical and physical concepts is known as Engineering Design. Would you want to learn more about Engineering because of this course?	11	1	• Yes because it was a learning experience • Yes, it seems fun and a good job • Yes, I would like to learn more about engineering because almost everything about this is challenging and is also fun

What challenges did you face when building your mousetrap car? How did you work through them?	• It [the axle] would stop but I made it smooth so it wouldn't stop • To stop my car from skidding, making an extra arm… changing my car's model • My mousetrap kept braking [sic]

What overall lessons did you learn from this elective?	• You can build with anything • How to make a mousetrap car and what friction is • How to set a mousetrap… formulas • If one mistake occurs when building something that structure could fail to operate

Conclusion

The potential of inquiry-based learning has been the focus of significant investigation in the past decade after it was prescribed as part of national education reform efforts. As a way to expedite the inclusion of inquiry approaches in K-12 science education, university outreach programs such as GK-12 recruit undergraduate and graduate students to aid instruction in K-12 classrooms. By working with teachers and preparing "hands on" classroom activities, GK-12 fellows contribute a deeper understanding of science to the classroom environment while providing an alternative to expository teaching styles [15]. As a result of increasing science literacy by providing extra teaching support and developing more interactive curricula, GK-12 programs aim to effectively increase the number of middle and high-school students considering science and engineering careers.

The reviewed studies favoring inquiry approaches on the basis of learning gains have been conducted primarily in mid-SES or suburban classrooms and are implemented in conjunction with the curriculum of a scheduled course. Though inquiry is strongly suggested to GK-12 Fellows as a teaching method for engineering concepts, it is difficult to carry out long-term projects in urban areas, which are subject to rigorous testing schedules unlike suburban schools. Since the aforementioned studies have not presented engineering concepts to students and gauged their interest, it is unclear if students may be interested in science and engineering as a result of inquiry-based learning. As engineering topics may be complex, it is of interest to GK-12 programs to determine the amount of scaffolding necessary to favorably introduce engineering to students as part of inquiry approaches.

An inquiry "module" was implemented in an urban classroom with the goal of engaging students with engineering concepts through directed activities. Students constructed an artifact (mousetrap-powered vehicle) and could perform experiments on the artifact as part of a re-design process. After iteratively adapting the course scaffolding to students' abilities, the revisions indicate that a fully-scaffolded approach to inquiry promotes student participation and achievement, particularly if the course is implemented on a volunteer (i.e. ungraded) basis. Results of the exit survey (Table 1) indicate that the majority of the students enjoyed the design-oriented approach of the course, would be interested in independently constructing their own projects, and would consider engineering careers.

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