An Overview of Secondary School Engineering Outreach Programs - Including Details of a Multidisciplinary Outreach Program Based on Integrating Digital Photography, Digital Electronics, and Roller Coasters

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Abstract:
Enrollments in post-secondary technology, engineering, math, and science have dropped off significantly and continue to decline. Student scores in math and science in the United States (US) are significantly lower than other developed countries. To alleviate these declines, schools are attempting to interest students from kindergarten to grade 12 (k-12) in technology, engineering, math, and science disciplines. Schools across the US have implemented a variety of formal programs such as Project Lead-the-Way in attempts to promote student interest in these fields. Additionally, technology and engineering have been introduced to middle and secondary school curriculums using a variety of less formal methods. For example, students can participate in structural load competitions, mousetrap powered vehicle racing, egg-drop competitions, model rocketry, hands on computer applications, and many other interesting endeavors revolving around technology. Through interactions with middle and secondary students, there is hope to successfully encourage young students to continue their post-secondary education in technological fields.

This paper begins by providing an overview of both formal and informal outreach projects at the middle and secondary school level in most of the engineering and technology disciplines. Brief descriptions of many student projects are included.

A community-based multidisciplinary outreach project involving a coordinated mix of digital electronics, digital photography, and roller coasters is then described in detail. This project was used as part of an outreach program coordinated by the Boy Scouts of America Explorers Program, the British Aerospace Systems Corporation (BAE Systems), and the State University of New York. This particular program provided multidisciplinary experiences over a very broad spectrum of technologies including electrical, automotive, civil, construction, architecture, mechanical, industrial, and computer disciplines.

Students began by building a large model roller coaster, which provided experiences in architectural, civil, construction, mechanical, and other related engineering technologies and

disciplines. The students then experienced concepts relating to automotive technologies by building the roller coaster vehicle and studying the impact of various weights and designs on the vehicle as it progressed around the track. To further their multidisciplinary query into computers and electronics, students constructed a digital roller coaster speedometer, as a method to determine the relative speeds of the vehicle at varying locations on the roller coaster track, and the impact of vehicle design and weight on speed. Digital photography helped students understand the relationship between electronic schematics and digital circuits, and assisted them in the construction of the non-trivial digit speedometer.

Introduction

Initiatives are under way across the US to counter the facts that math and science scores of US students are lagging those of other developed countries, and enrollments in post-secondary technology, engineering, math, and science are declining. The importance of insuring that middle and high school students are introduced to engineering disciplines is expanding at all levels including informal programs offered at individual schools; formal programs offered by non-profit organizations including professional organizations, colleges, and universities; and formal state and national initiatives. Schools across the US have implemented a variety of formal programs such as Project Lead-the-Way in attempts to promote student interest in these fields. Many formal initiatives are being undertaken at the state and federal levels, including legislation to insure pre-college students are exposed to science, engineering, and technology. Formal initiatives are also underway at the federal level, and include federal legislation to insure pre-college students are exposed to science, engineering and technology. Other formal initiatives are being sponsored by professional organizations such as The American Society for Engineering Education (ASEE)**.** Additionally, many colleges and universities are actively engaged in k-12 outreach programs.

A variety of less formal methods has been introduced in middle and secondary schools to introduce students to technology and engineering. For example, individual instructors have introduced engineering and technology by establishing course content where students participate in structural load competitions, mousetrap powered vehicle racing, egg-drop competitions, model rocketry, hands on computer applications, and many other interesting endeavors revolving around technology.

The outreach project described here is a mix of both formal and informal methods. This project was coordinated by several different organizations, and consisted of a mix of digital electronics, digital photography and roller coasters. It provided multidisciplinary experiences over a very broad spectrum of technologies including electrical, automotive, civil, construction, architecture, mechanical, industrial, and computer disciplines.

An Overview of Secondary School Outreach Programs.

Formal Outreach Methods:
Many engineering technology outreach methods exist, ranging from very informal discussions in classrooms, to very formal endeavors such as Project Lead-the-Way (PLTW). PLTW is a national program forming partnerships among public schools, higher education institutions and the private sector to increase the quantity and quality of engineers and engineering technologists graduating from US schools. PLTW has developed a four year sequence of courses which, when combined with traditional mathematics and science courses in high school, introduces students to the scope, rigor and discipline of engineering and engineering technology prior to entering college. The courses are Introduction to Engineering Design, Digital Electronics, Computer Integrated Manufacturing, Principles of Engineering, and Engineering Design and Development. Providing a technology based introduction at this level will attract more students to engineering, and will allow students, while still in high school, to determine if engineering is the career they desire. The PLTW graduate will be better prepared for college engineering programs and will more likely be successful, thus reducing the attrition rate in these college programs, which currently exceeds 50% nationally. In addition, PLTW has developed a Middle School Technology Curriculum: Gateway-To-Technology. This project-based curriculum is 40 weeks in length and is divided into four 10-week units: Design and Modeling; The Magic of Electrons; The Science of Technology; Automation and Robotics. Designed for all students, the units address national standards in math, science and technology. One of the goals is to increase interest and awareness to all students, but particularly female and minority students in technology and related careers. Gateway-To-Technology will also encourage an increasing number of middle school students to elect the high school level PLTW program [1].

Acknowledging the need for pre-college engineering and technology, at least seven states have already placed pre-engineering into their k-12 curricula, and others are sure to follow.
Formal federal initiatives include legislation from the Education Reform Act of 1993 and the No Child Left behind Act of 2001[2]. Other formal initiatives are being sponsored by professional organizations such as The American Society for Engineering Educators (ASEE) [3], The American Association for the Advancement of Science, and The American Society of Mechanical Engineers. Organizations such as the National Science Foundation Math and Science Partnership Program and NASA also have funded and/or established formal outreach programs [2]. In addition, colleges and universities including Lawrence Technological University [4], Tufts University [5], Arizona State University East [6], New Jersey Institute of Technology [7], Iowa State University [8], Miami University –Ohio [9], Lehigh University [10], University of Missouri-Rolla [11], and The University of Texas at Brownsville [12] are actively engaged in k-12 outreach programs.

Informal Outreach Methods
Less formal outreach techniques have been introduced in middle and secondary schools to introduce students to technology and engineering. Several of the more common techniques are described below. Most of these techniques can be accomplished for very little cost using very

commonly found materials. Companies such as Pitsco sell complete kits for many of these projects [13].

Structural Load Competitions

Structural load competitions can be used to stimulate student interest in civil, construction, and architectural engineering technologies. Students are provided with the materials and guidelines for building a structure capable of carrying the highest load. The guidelines can range from absolute free-form construction, to rigid dimensional specifications. Balsawood (and glue) or toothpicks (and gumdrops) are typical structural materials used for construction. A competition would determine which structure is capable of carrying the highest load. Uncooked spaghetti is also a good choice for a structural material, and even though it is less uniform than balsawood, it avoids the inherent dangers of using cutters to cut the structural components to length. Companies such as Pitsco sell competition kits, cutters, and load measuring systems for structural load competitions [13].

Mousetrap powered vehicles

Mousetrap powered vehicles promote interest in automotive engineering technology, mechanical engineering technology, and related fields. Students are provided with the materials and guidelines for building a vehicle that is powered by the spring mechanism of a mousetrap. These vehicles are typically raced for speed within a specified distance, or for overall distance traveled.

Egg-drop competitions

Egg-drop competitions have been used to promote interest in mechanical, architectural, and civil engineering technology, and related disciplines. Students are provided with guidelines for building a structure capable of protecting a raw egg in a fall from a pre-determined height. The guidelines can range from absolute freeform construction, to rigid dimensional and materials specifications. Specifications for materials can range from Balsawood to completely freeform construction, where students are allowed to use virtually any materials to construct the structure.

Model rocketry and model aircraft

Model rocketry and model aircraft have been used to pique interest in aeronautical engineering technology and related disciplines. Model rocketry is typically accomplished with kits that can be purchased from a variety of sources. Students are allowed to paint and assemble the rockets in a variety of fashions. Typical competitions are for the highest flights, or the accuracy of descents. Model aircraft construction can take many forms. One typical scenario is to provide plans to students (with alternative options) for building a model glider from free-form pieces of wood. Competitions typically are for distance, time in flight, or flight accuracy.

Rocket motor propelled land vehicles

Rocket motor propelled cars can be used to pique interest in automotive engineering technology, aeronautical engineering technology, and related disciplines. Students create a 4-wheeled car from a block of wood using jigsaws, sanders and a drill. Students are allowed to form, paint, and assemble the rockets in a variety of fashions, with or without limitations. These vehicles are typically raced for speed within a specified distance.

Hands on computer applications
Nearly every student receives exposure to computers prior to completing a high school diploma. This exposure alone does not seem to pique an interest in computer engineering technology or computer science as a profession. Further exposure other than video games, simple spreadsheets and word processing are needed to stimulate students. Showing students how to create their own websites is one method of generating interest in computing. Easy to use website creation software such as Print Shop [14] is very good at the high school level. The skills required for computer programming can be explored in a variety of fashions including the use of the Lego Mindstorms Robotics System [15] that utilizes a relatively easy to use graphical programming interface rather than a traditional line-by-line (complex) programming language.

Multidisciplinary Experience Integrating Digital Photography, Digital Electronics, and Roller Coasters

Formal programs such as Project Lead-the-Way are unfortunately not available at many high schools. Lack of trained teachers, high costs, and many other factors prevent many schools from participating in such formal endeavors. Informal outreach methods such as those discussed earlier are a good start to encourage students to consider engineering and technology careers, but more needs to be done.

In an attempt to blend some of the informal and formal outreach methods, an outreach program was begun in an attempt to bring together students from varying schools and backgrounds in the Binghamton, New York geographical region referred to as the Southern Tier of New York. This outreach program was hosted by the Explorers Program of the Boy Scouts of America, sponsored by British Aerospace Systems (BAE Systems) in Johnson City, New York, and assisted by the T. J. Watson School of Engineering and Applied Science at the State University of New York at Binghamton.

The Boy Scouts of America (BSA) hosts Explorer Posts across the United States. Exploring is the young adult division of the Boy Scouts of America, and is open to young men and women between 14 and 20 years old. In Exploring, community organizations or businesses team up with a local Boy Scout Council to provide a program that typically reflects the possible career interests of the youth in an Explorer Post. Such a Post may specialize in any area of expertise such as engineering, space exploration, law enforcement, etc. For example, an Internet Service Provider could sponsor an Explorer Post specializing in World Wide Web programming and invite young people with an interest in web programming to join. The sponsor supports the program by providing a meeting place, adult advisers, and program support in the form of consultants or instructors in particular areas [16,17,18].

The BSA conducted a career interest survey at schools within the Southern Tier of New York. From the survey, those students indicating an interest in engineering or technology were invited to join the Engineering Explorers program hosted by BAE Systems in Johnson City, New York.

Including joint ventures, BAE Systems and BAE Systems North America employs more than 90,000 people worldwide. BAE Systems designs, manufactures, and supports military aircraft, surface ships, submarines, space systems, radar, avionics, electronic systems, guided weapons and a range of other defense products. The company also develops, integrates, and produces test equipment for advanced electronic systems including space launch, satellites, and avionics systems. Software development is a key activity that involves more than 10,000 systems software engineers. The company's research and development projects cover the spectrum of technologies, materials and synthetic environments, such as virtual reality and 3-Dimensional modeling [19,20].

Weekly seminars were held at BAE Systems, and included speakers and hands-on projects (described later). Binghamton University provided assistance with several of the hands-on projects. Binghamton University (BU) is located in Binghamton, NY and is one of four university centers within the 64-campus State University of New York system. BU consists of six schools and colleges, including the T. J. Watson School of Engineering and Applied Science, and twenty-four specialized research centers [21].

The Roller Coaster

A model roller coaster was utilized to stimulate overall interest in engineering technology, especially in the areas of automotive, civil, structural, construction, and mechanical engineering technology. Roller coasters can provide experience in structural design and analysis, construction techniques, friction, motion, mathematics, physics, centrifugal force, etc. The first task was for students to construct the model roller coaster. One distributor of model roller coasters is GDJ Inc.[22] The GDJ coasters are very high quality professional grade models costing up to $9,800 each, and is shown in Figure 1. The roller coaster chosen for the outreach program was a model that is available from K'NEX Inc.[23] K'NEX offers several types of roller coasters ranging in price from $60 to $250. One of the models available is shown in Figure 2. The model used in this outreach program is quite large for a toy, measuring approximately 2.5 feet high, 2.5 feet wide, and 5 feet long. The K'NEX kit consists of many small plastic parts that snap together as beams, trusses, and columns to form structures of any shape or size. A flexible track is included that connects to the structure to form the track for the roller coaster vehicle.

To begin the project, the students were divided into four teams ranging from 5 to 8 members. Each team was provided with the construction plans, and the necessary parts to build a K'NEX roller coaster. The teams were allowed to deviate from the basic K'NEX design in any manner they chose, to create a roller coaster of their own design.

For example, to achieve a higher track speed, some teams attempted to build their coaster such that the downward slopes were steeper than the K'NEX design. The students soon learned that the Roller coaster car would fall off the track when the velocity of the car exceeded a certain speed. This was certainly a good experience in the physical sciences.

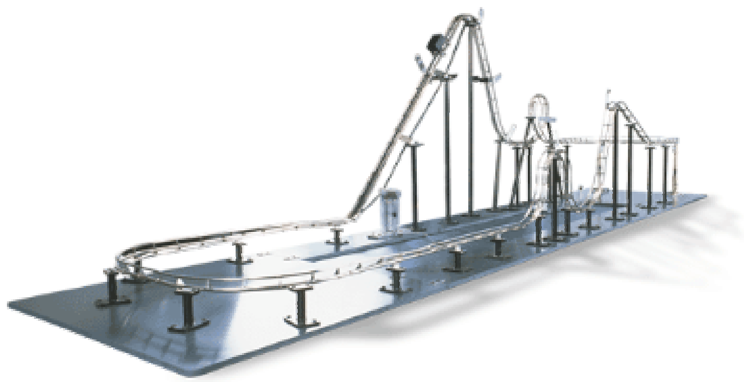

Figure 1: The Professional Level GDJ Inc. Model Roller Coaster [22]

Several teams modified the roller coaster vehicle to make it lighter or heavier than the K'NEX design. Once again, students learned valuable lesson in the physical sciences when they observed that vehicles that were too light or two heavy either fell off the track, or were not able to complete the journey around the entire track.

Figure 2: K'NEX model Roller Coaster [23]

The Electronic Speedometer

An electronic speedometer was incorporated into the roller coaster project for several purposes. Just the fact that the students would be able to measure the speed of the roller coaster vehicle, made the roller coaster a more exciting and knowledgeable experience. In addition, the speedometer was a bit-level digital system designed and supplied by BAE Systems, which had to be completely assembled by the students. This provided the students with an opportunity to learn about digital electronics and electrical engineering technology, computers and computer engineering technology, and interfacing an analog system (the roller coaster vehicle) to a digital system (the speedometer).

The speedometer was actually just an eight bits, base 16 counter. The input was a photocell that could detect the presence or absence of a stimulus, where the stimulus was the roller coaster vehicle passing through it. The photocell input started (or stopped) a function generator, which in turn started (or stopped) a binary counter connected to two 7-segment displays that displayed two base-16 digits.

The logistics of building a non-trivial circuit by students with absolutely no knowledge of logic or electronics was a large obstacle that had to be overcome. The students were provided a schematic, but without any background, it meant nothing to them at first. The students needed some kind of systematic method to construct the circuit.

Digital Photography

Digital photography became the solution that overcame the logistics of building a non-trivial circuit by students with no knowledge of electronics or logic. Full color digital photographs of each step of the construction phases were provided to the students. All wiring was color-coded for the purpose of reducing the complexity of photographs used for constructing the circuit. The photographs clearly displayed each and every hole of the breadboard, the exact placement of the integrated circuits, wiring, and electrical components. Each photograph was accompanied by a matching schematic, so that the students could understand the relationship between the physical construction of the circuit and its design. Seventeen digital photographs were provided to students to assist them in the construction of the eight steps required to complete the electronic speedometer. Each of the steps had one or more digital photographs (Figures 3 and 4) and an accompanying digital system schematic (Figure 5) that matched the digital photographs. As the circuit construction became more complex, multiple views of the same step of the circuit building process would be utilized, typically consisting of a close-up photograph of the step in progress, and a wide-angle of the entire circuit up to that point in the construction.

The steps necessary to construct the speedometer circuit:

1. Identify and gather all of the necessary parts to build the circuit.
2. Install the battery (a 9-volt battery was used as the power source), on/off switch, and photo-optical input sensor.
3. Install the clock.
4. Install the counter.
5. Install the driver for the first base-16 digit.
6. Install the first base-16 digit.
7. Install the driver for the second base-16 digit.
8. Install the second base-16 digit.

Figure 3 shows a wide-angle view of Step 6, Figure 4 shows a close up view of Step 6, and Figure 5 shows the schematic for step 6, that matches up with Figures 3 and 4. The finished circuit is shown in Figure 6.

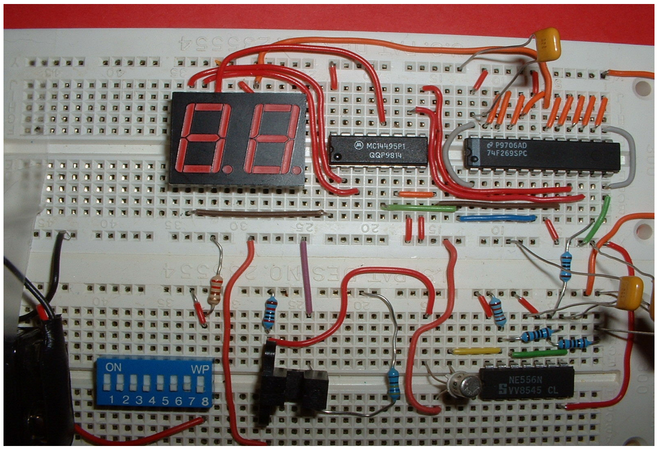

Figure 3: A wide-angle view of Step 6; install the first base 16 digit

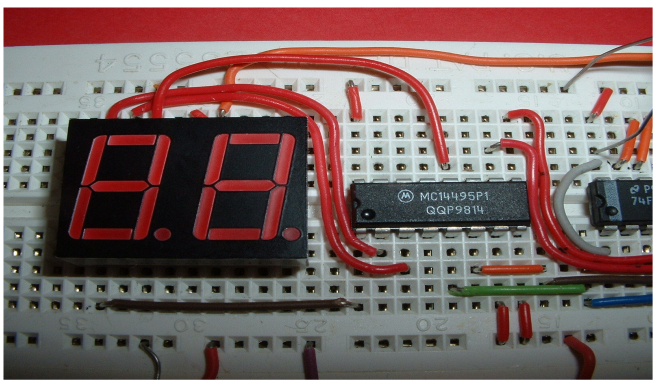

Figure 4: A close up view of step 6, install the first base-16 display

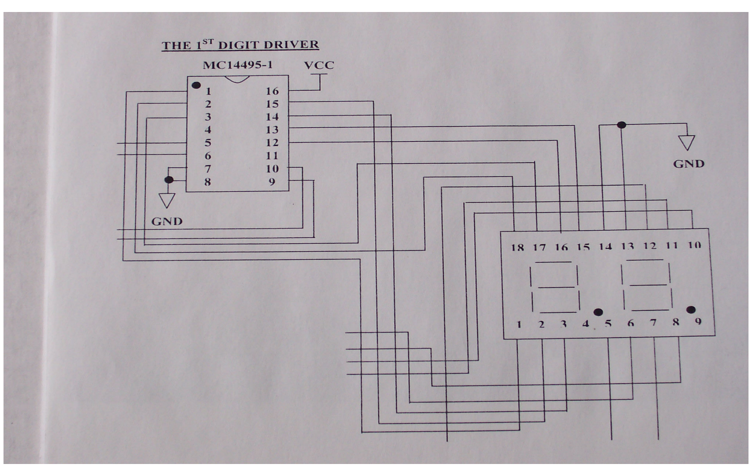

Figure 5: Circuit schematic that matches the digital photographs of Figures 3 and 4.

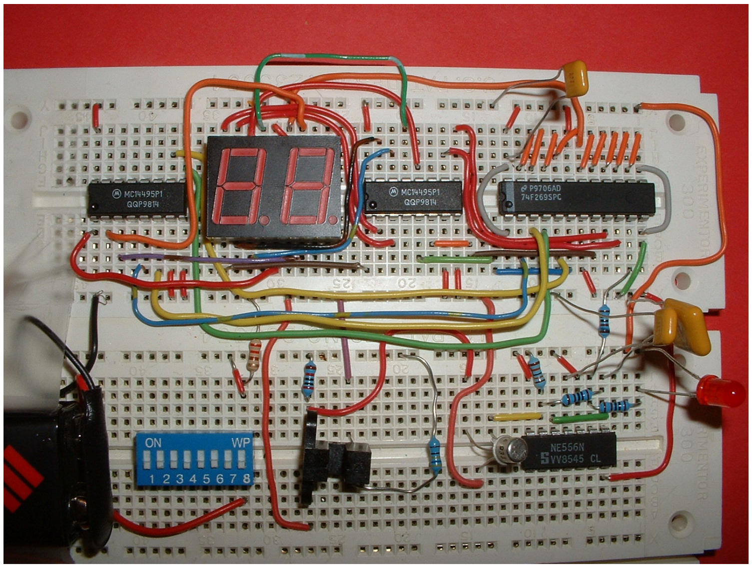

Figure 6: The finished circuit.

Conclusion:

Many students have enjoyed learning about engineering and technology by building at least one of the devices discussed in the informal outreach section of this paper.

The roller coaster was a big hit with the students in this outreach program. The use of digital photography certainly made the construction of the circuit an achievable goal. Connecting the speedometer to the roller coaster was a great way to integrate the many engineering disciplines involved in each phase of the project.

As the economy falters, as engineering and technology jobs move offshore, and too many H-1B visas are granted; the unemployment rates in engineering fields remain uncharacteristically high[2]. Anecdotal evidence points to a correlation between these high unemployment rates and the decline in college enrollments in many engineering and technology fields. Prospective students are not willing to make the sacrifices necessary to study engineering, when a job upon graduation is no longer guaranteed. This is not a time to back down on outreach programs. In fact, this is the time to increase efforts in order to show students the advantages that do exist in careers in engineering and technology.

Certainly formal programs such as Project Lead-the-Way are outstanding methods to introduce secondary school students to engineering and technology. However, not all outreach activities have to be as expensive or time-intensive as Project Lead-the-Way. Programs such as the BSA Explorers Program are very effective at showcasing engineering and technology to students. Even simple exercises such as egg-drop competitions, model rocketry, or spaghetti bridges are invaluable when used to introduce pre-college students to engineering and technology.

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Biography

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