Integrating Engineering Ideas into High School and Middle School Curricula

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Abstract

Professional development to introduce high school and middle school math and science teachers to engineering design projects that can be readily used in the classroom was held at TCU in July 2008. The goal of the staff development was to enrich teacher content knowledge of engineering, physics, and mathematics concepts through discussion and activity. The participants represented several local public and private schools. Projects included: the construction and launch of model rockets and prediction of their maximum height; building small electric motors; a brief discussion of internal combustion engines; team design, construction and testing of model trebuchets; a team heat transfer minimization design, construction and test exercise using recycled materials not specifically designed to be used for insulation; and a team wind chime design, construction and test exercise. As a group, the teachers brainstormed ways that these projects could be used at their schools after each project. Preliminary results indicate that the workshop was very successful, and some of the projects are being employed in classrooms.

Introduction

The research on professional development has shown that teachers respond positively to training that includes content knowledge preparation in a hands-on context that includes problem-solving activity.[1] Longer, extended sessions in which there are opportunities for in-depth discussion and activity that includes pedagogical practices are considered more successful than the workshop counterpart.[1] According to Supovitz and Turner[2], "high quality professional development must immerse participants in inquiry, questioning, and experimentation and therefore model inquiry forms of teaching." The goal of this professional development was to offer a two-week-long training opportunity which provided teachers with numerous challenging explorations that broadened their knowledge and experiences related to engineering, physics, and mathematics. Further, if the teachers learned from and enjoyed their experiences, they would be more likely to adapt training-session investigations into their own classrooms---thus, students would be the ultimate beneficiaries.

The prototype for the project was created by Michael Yakubovsky, a science teacher in Coppell Independent School District. He created a four-year pre-engineering program (EXCITE) at Coppell High School that combines the faculty's talents and knowledge of mathematics, science and technology and their desire to work on meaningful projects. Since implementation, the pre-engineering program at Coppell ISD has been recognized as a highly successful endeavor, and student enrollments have ballooned. We visited with Mike regarding the pre-engineering program and discovered that many of the investigative activities could be readily integrated into already existing physics and mathematics curricula as well as pre-engineering classes. We proposed to conduct an 8-day summer training session for middle school and high school science and mathematics teachers from area schools. We had conversations with school districts (and private schools) as well as Coppell and determined that the schools were receptive to this type of teacher training. Many high school and middle school teachers were eager to bring engineering ideas into their classrooms especially if the engineering ideas could be illustrated with a good hands-on exercise. Our workshop was created to bring Mike's experience, complemented by some background knowledge and a few more self-contained exercises, to a larger group of teachers. Since Coppell High School's program has been so successful at creating collaborative teams of mathematics, science and technology teachers, we invited teams of mathematics and science teachers from local high schools and middle schools to attend the workshop.

Theoretical material and organized discussions were scheduled for the morning, saving labs and hands-on exercises for the afternoons. Time was scheduled after every major exercise for the participants to discuss opportunities for them to teach using that exercise. The "brainstorming" was recorded and facilitated by the exercise presenter.

Projects

The projects were based on model rockets, trebuchets, heat transfer minimization (insulation), and wind chimes. In addition to the projects, the workshop participants also learned about new Texas teacher certification opportunities, design project management principles from the instructors' and design team's perspectives, small electric motors, internal combustion engines, and academic expectations of university engineering programs.

Model Rockets

Model rockets provide an ideal instrument for teaching several basic physics concepts while keeping the students interested. There are many helpful supplements available. Some of the best are found at www.esteseducators.com. During our workshop, each teacher was challenged to build a rocket to maximize its height after launch. Figure 1 shows one of the rockets being launched. Many were surprised how easily the construction and launching exercises were completed. We discussed the theoretical principles of rocket trajectories, rocket motor burn rates and thrust.

The teachers also measured the thrust of their rocket motors using a simply constructed measurement setup. The testing device consisted of a disposable, plastic drinking cup;

expanding, polyurethane foam insulation; and a force plate. A Vernier force plate[3] and laptop were used in the workshop, but the same results can easily be obtained with the use of video camera and scale. The rocket motor was held in the cup by the foam and set on the force plate. The thrust of the motor was easily measured and analyzed later. The actual time vs. thrust curves of the rockets can be found on the manufacturer's website.[4]

Figure 1. A rocket launch.

Model Trebuchets

Trebuchets are excellent vehicles for teaching mechanics. There are several sources describing the construction and testing of trebuchets;[5,6] Professor Alejandro Garcia's website www.algarcia.org/teaching.html was especially helpful. The teachers formed three teams and were asked to design and build a trebuchet using 2" by 4" lumber with a ¾" diameter metal rod (for the crossbar) that would maximize projectile (tennis ball) throwing distance and be adjustable so that the same design could throw a given distance. The finished trebuchet was required to be less than 2' tall at the crossbar. The experiment included a closest-to-the-pin and an efficiency contest. This added an element of fun and excitement to the demonstration of the basic principles. A picture of one of the trebuchets being "fired" is shown in Figure 2.

Heat Transfer Minimization (Insulation)

This experiment demonstrated the principles of heat transfer by conduction, convection and radiation. The exercise began by examining these three heat transfer modes to understand how they work.[7,8] The objective of the experiment was to design and build an "insulation system" that would keep an open can of liquid cold for 1 hour. The teachers worked in teams. The "insulation system" had to be constructed from re-cycled materials that came from home or could be found in the lab. None of the materials could be purchased. Materials originally designed specifically for insulation could not be used. Aluminum foil and masking tape were supplied.


Figure 2. A trebuchet in action.

The major design constraints were that the “insulation system” must fit within a 12in x 12 in x 12in volume and allow for the passage of a thermocouple wire from the open hole in the top of the can to the data collecting instrumentation; the system had to be able to maintain initial temperature for one hour with no more than a 10° F gain when exposed to a heat source from above; the system must be constructed and tested within a 2 hour period; and the initial temperature of the liquid had to be ≤ 40° F. The heat source was an infrared lamp placed 13 inches above the table top and potentially 1 inch from the “insulation system” if the design was constructed to maximum dimensions. A wide variety of designs and performance resulted.

Wind Chimes

Wind Chimes were used to demonstrate the concepts of vibration, resonance and harmonics. It also introduced the concepts of measurements in the time and frequency domains.[9] The exercise began with a discussion of vibration of solid materials that vibrate the air and eventually produce the sounds that become music to our ears.[10] The basic governing scientific principles and equations were introduced. [11,12] Using these equations, the teachers then designed sets of wind chimes using lengths of aluminum pipe, string and a wooden disk. They selected a set of complementary notes and then calculated and cut the length of the pipe necessary to produce the desired frequency of each of the notes. Each length of pipe was struck at anti-nodes and supported at the nodes.[13,14] The sound was captured using a microphone, laptop computer with a sound card and SigView software[15] that displayed the output on the computer in the time domain and converted the display to the frequency domain. This set-up allowed the teachers to compare their actual results to their theoretical calculations. It also produced a product that was fun and provided immediate feedback.


Figure 3. Final assembly of an effective insulation design.

Summary and Conclusions

To determine the effectiveness of the professional development, teachers who participated took pre- and post- content tests and completed a written evaluation of the workshop. We focused on conceptual understanding and problem-solving applications rather than specific factual knowledge. All teachers improved on their pre- to post-test scores with the exception of one (and his test score remained the same). Overall mean scores improved from 70% to 77%. Scores on the pre-test ranged from 48% to 91%; on the post-test, scores varied from 57% to 93%. Written evaluations revealed that none of the teachers had attended a workshop that combined engineering, mathematics, and physics in an integrative curriculum that could be implemented in one or all of the classes. Not all of the teachers indicated that they have the requisite materials to carry out some of the activities, but all of them revealed that they had found at least one activity they wanted to try in their classes. Later communications from several teachers indicate that they have replicated from one to two of the activities in their own classrooms (e.g., electric motors and heat transfer experience).

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