AC 2007-2866: ENGINEERING TEACHING KITS: BRINGING ENGINEERING DESIGN INTO MIDDLE SCHOOLS

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Engineering Teaching Kits:
Bringing engineering design into middle schools

Abstract

Engineering Teaching Kits (ETKs) introduce engineering concepts and methods into existing middle school science and math classes. We identify topics from science, math, and technology that have interesting engineering applications, and then help students learn science and math in the context of engineering design. Each ETK includes real world constraints (budget, cost, time, risk, reliability, safety, and customer needs and demands), and each involves a design challenge that requires creativity and teamwork.

Over the past five years, we have developed and field – tested twenty - five Engineering Teaching Kits (ETKs). So far over 2000 middle school students and 30 middle school teachers have used these materials. The ten most popular and thoroughly tested ETKs are being revised and elaborated for national distribution in electronic form (CDs, DVDs, and Internet). Our goal is to make each ETK complete and readily useable by teachers without our presence.

In this paper, we review the processes and strategies for developing ETKs, and discuss how the structure of an ETK has evolved based on student performance and teacher feedback. We also provide three examples of successful ETKs.

Background

The United States is suffering from a national crisis in science and math education. At the middle and high school level, our students perform poorly on standardized tests in comparison to other developed countries. And too few of them choose to pursue studies in engineering, math, or science at the university level. Engineering programs nationally have experienced declining enrollments for almost two decades. In addition, women and minorities are still under-represented in many technical fields, especially in engineering.

How can we recapture student interest in science, math, and engineering? How can we attract students from all segments of our diverse population? Middle school is the key; this is the time when many kids decide they are not interested in science, or not good at math. Most never get the chance to learn about engineering.

For the past five years, we have been working with middle school teachers to bring engineering teaching kits into their classrooms. An Engineering Teaching Kit (ETK) is a set of lesson plans focused on a well-defined set of concepts in science or math. What makes these lesson plans unique is the final Design Challenge. The students must use the knowledge and methods they have learned to design and build something.

Every ETK introduces the engineering design process, and each requires middle school students to design and build a device, machine, or system to achieve a goal. Each ETK includes hands-on experimentation, data gathering and summarization, and evidencebased reasoning. The middle school students work in teams on a series of tasks and projects. The ETK is carefully constructed to guide the students' learning of particular concepts and methods. The pedagogical technique is a variety of constructivism, known as 'guided inquiry'[1].

Educational Standards

Although most states have educational standards for science and mathematics, only a few require technology or engineering knowledge and skills among K – 12 students. Massachusetts is the exception; its Curriculum Framework involves engineering and technology at all grade levels. At the national level, the International Technology Education Association (ITEA) standards have led to curriculum materials to introduce engineering in middle and high schools (http://www.iteaconnect.org/). Our ETKs are designed to meet state and national standards in science and/or math, and when appropriate to also meet the Massachusetts and ITEA standards. Each ETK includes a list of the specific standards addressed.

The ETK Design Process

The ETKs are developed by teams of fourth year Mechanical Engineering students in a year long capstone design class. For the last five years, this experimental class has been offered as one of several options for meeting the capstone design requirement. During our last ABET visit, the examiners reacted positively to this course sequence. We have now formally submitted these courses for review, and they have been approved by the engineering school faculty as part of our regular curriculum. However, in response to input from our department's design committee, we have introduced a product design project in addition to the Engineering Teaching Kit. We have also expanded the syllabus to include manufacturing, entrepreneurship and business concerns. This year, the entire first semester was devoted to developing ETKs; the second semester includes testing and revising the ETK and then a new product development project.

Our senior design options (MAE491D/492D) now attract over half of the fourth-year students in Mechanical Engineering. In the first five offerings of the course, over 170 fourth year students have participated in developing engineering teaching kits. Graduate students from the Curry School of Education and undergraduates from other engineering departments (Civil, Biomedical, and Electrical) also participate under a separate course number (ENGR 591/592). These courses are now being offered for the sixth time; 35 new students are enrolled and six ETK teams have developed their lesson plans. They are now (Spring 2007) testing their ETKs in local middle schools.

At the start of each new academic year, we review all the existing ETKs and analyze why some succeeded and others did not. We work through a few ETKs as a class. Students have the option of improving on prior projects, or developing new ones. Most teams decide to pursue novel ideas, although they incorporate features of existing ETKs into their designs. The class generates potential topics for new ETKs, and then teams form around a few of these ideas. These teams then develop lesson plans and a design challenge for their topic.

After the initial set of lesson plans are developed, they are distributed to the entire class for review and comment. The instructors also provide input on the early drafts. When the team has revised their ETK, we have them solicit reactions from middle teachers and graduate students from education. During this process, the team is making contacts that will result in actually testing their ETK in a middle school class. When a middle school teacher feels the team is ready, they go into the classroom. The first version of each ETK is always taught by the team that developed it. They are accompanied by one or more observers, and the classroom teacher is present during the lessons. We ask each teacher to provide comments and reactions on the use of the ETK in their class, and to suggest ways to improve it. We also ask whether any problems might arise in using the ETK. Finally we want to know if the teacher feels he or she could use the ETK without our team present.

Members of the design team also reflect on how they think the field test went. Based on all this feedback, the team prepares the next version of their ETK. We continue to improve and elaborate ETKs as they are used in various contexts and with different audiences.

ETKs

Over the past five years, we have developed and field – tested twenty-five Engineering Teaching Kits (ETKs). Several other ETKs have been designed but not yet tried in the schools. These will be further refined by future classes. The ten most popular and thoroughly tested ETKs are being revised and elaborated for national distribution; they are

- *Under Pressure:* Designing submersible vehicles.
- *RaPower:* Designing and building model solar cars.
- *Brainiacs:* Brain tumor treatment technology.
- *Catapults in Action:* Designing catapults for distance and accuracy.
- *Aerospace Engineering:* Designing planes and rockets.
- *Bio - Mech - a – Tek*: Designing prosthetic devices to achieve arm functions
- *Get Stressed*: Building bridges from everyday materials
- *Crane Corp*: Simple machines performing complex tasks.
- *Filtering Ideas:* Designing a water filtration device.
- *HoverHoos:* Hovercraft design.

ETK: some examples

Previous papers [2, 3] described the initial three engineering teaching kits in detail: *Under Pressure* (submersible vehicles), *RaPower* (solar cars), and *Brainiacs* (devices for brain surgery). These provided the template for all subsequent ETKs, and their use helped establish the ways we interact with the schools. In this paper, we will briefly illustrate ETKs with three more recent examples.

HoverHoos

In the HoverHoos ETK, the middle school students learn how a hovercraft works. The two main concepts are the loss of friction and propulsion using forced air. Demonstrations of several hovercrafts (both homemade and commercially available) show students how each hovercraft involves the same concepts. Then they learn about propulsion and Newton's Laws of Motion as they pertain to Hovercrafts. We present Newton's three laws of motion and examples to illustrate each. Friction, force, acceleration, drag, and propulsion are discussed and demonstrated, and then students fill out a worksheet - connecting propulsion and Newton's Laws.

Students are provided with different materials to design and build their hovercrafts. They can apply the concepts they learned during the week to design the most effective hovercraft to perform in a series of tests. The materials used for this ETK are available from a commercial vendor (www.kelvin.com) as a kit. However the primary materials one needs to purchase are propellers and motors.

All teams are subject to the following Design Constraints:

- Each team could use up to 3 motors
- Each team could only use 3 propellers
- Each team could only use 2 batteries
- Small Items may be brought from home to use in the design

The students tested their hovercraft's ability to travel a true path. Each team is awarded points based on successful completion of the course, trueness of the path traveled, and speed. Following testing, the groups participate in a "Jeopardy" game where they are also awarded points for the questions they answer correctly. The group with the highest total score at the end of the competition and the game receives a prize.

Catapults in Action

The Catapult ETK was developed in response to a teacher's request for a unit on projectile motion. It has become our second most popular ETK (the Solar Car is first). In these lessons, students learn energy principles, including kinetic and potential energy, and examine the basic equations governing energy. The UVA team leads a discussion of the Law of Conservation of Energy and the SI unit system. The students complete an activity on spring constants and potential energy. Next students are introduced to simple machines, specifically levers and how they apply to catapults. Finally they gain an interactive, conceptual knowledge of projectile motion through experimentation. Students investigate how angles affect horizontal and vertical velocity, and conduct several types of scientific experiment using catapults.

Figure 1: Teams of students and their Hovercraft Designs

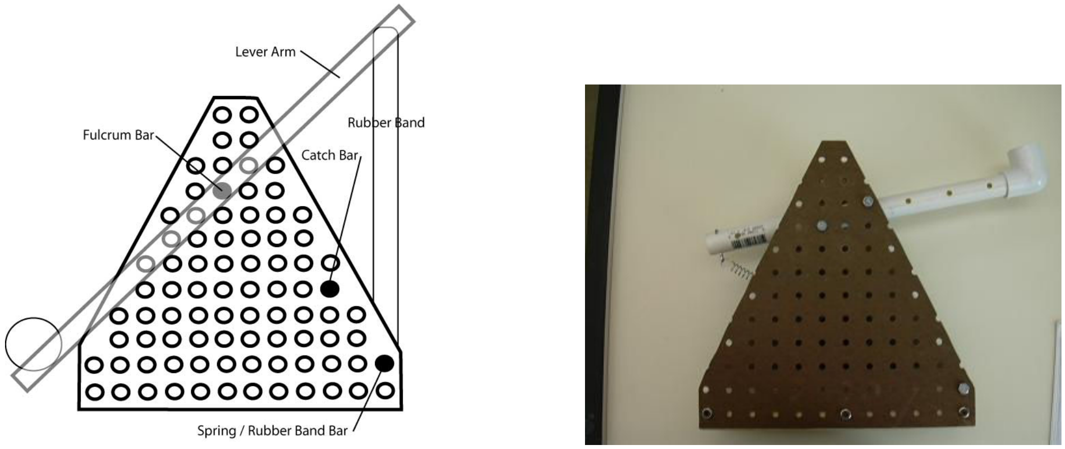

Figure 2: The conceptual design and realization of a catapult

Figure 3: About to launch

On the fourth day, students are introduced to the design competition, and begin design of their team's catapult. They must perform two distinct tasks with their catapults. We have a model castle set up in the school cafeteria. The first task requires the team to throw a payload over the castle wall and as far into the castle as possible (distance competition). The second task is to hit a particular turret on the castle (accuracy). The students are excited by the challenge and conduct many trials to determine the best settings and angles for each task.

This ETK has been used in high school as well as middle school classrooms. At one school, a team of teachers collaborated to use this unit for an interdisciplinary project involving science, math, English, and history.

Filtering Ideas

In this unit, students learn about the different contaminants present in our water, how these contaminants can affect human and animal life, and how to test for and remove some of them. By the end of this unit, students understand how to identify contaminants and build a filter to purify a water sample.

The daily lessons for this ETK are summarized below:

Day 1 – Water and Engineers
Objective: To understand the water cycle, how water is cleaned, and to introduce the engineering design process.
Key Concepts:
- The importance of water purification and the engineer's role.
- The engineering design process.

Activities:
- Conceptual design project.

Day 2 – Chemical Contaminants
Objective: To learn about the causes and dangers of various contaminants, how to test for them, and how to remove them.
Key Concepts:
- Aspects of pH, ammonia, and chlorine.
- Contaminants are removed through testing, filtering, and neutralization.

Activities:
- Lessons in chemical testing.

Day 3 – Alternative Designs
Objective: To learn about how design works under constraints, and for students to begin their own design project.
Key Concepts:
- Terafil, its simplicity and its effectiveness.

Activities:
- Introduce, assign teams, and begin the design project.

Day 4 – Design Project
Objective: For students to apply what they have learned to developing their own water filtration system.
Key Concepts:
- The importance of teamwork.
- Practical application of previous lessons.

Activities:

- Students work on their filter designs.

Day 5 – Competition and Review
Objective: To test the students' filtration systems and summarize the unit.
Key Concepts:

- Contaminants, their causes and dangers.
- Testing and purification techniques.

Activities:

- Design competition and review.

The materials for this ETK include: supplies for making filters: PVC pipe, cloth, coffee filters, mesh screen, duct tape; and the chemical testing kit: 5-10 pH testing strips, 2 ammonia testing strips, 2 chlorine testing strips; 1 eye dropper containing pH increaser, 1 with pH decreaser, 1 with chlorine remover, 1 with ammonia remover; and latex gloves and goggles for each student.

The water filtration ETK has been used in only one school so far. It is included here to emphasize that ETKs are not limited to the physical sciences. Seventh grade is usually focused on earth and life sciences, and, of course, engineers make important contributions to these areas.

Current ETKs

This year, six new ETKs are being developed:

1. Electricity Rocks! In this ETK, students explore the technological applications of electricity, magnetism, and sound. For their engineering design challenge, they design, build, test, and optimize a simple electro-mechanical speaker.

2. Surf's Up! How do engineers design structures to withstand tsunamis and coastal flooding? Students learn how science explains and predicts the interactions and dynamics of complex Earth systems. Key concepts include tectonic processes (subduction, rifting and sea floor spreading, and continental collision). Engineering fundamentals include hydrostatic (water) pressure, kinetic and potential energy, and building design. Teams of students will design and construct structures to withstand a simulated tsunami/hurricane that brings flooding to a specific area.

3. Save the penguins After learning about energy and heat transfer, teams of students construct and insulate a cardboard house to protect "penguins" inside from an artificial sun. Each team is given a base kit of materials (cardboard house with wire mesh base and different insulators), and a budget to purchase more materials as they see fit. The monetary constraints force students to evaluate the different options for insulation, and assess the best investments.

4. Sound Waves. Students learn the fundamental of concepts and properties of sound, and then design and build a musical instrument from everyday materials.

5. ***A Warmer World?*** is a five day lesson plan which teaches basic heat transfer and engineering design by studying the causes and effects of global warming. The lesson culminates with a design project in which students try to control the temperature of a system set up to mimic earth's atmosphere by applying the principles of heat transfer.

6. ***The Polarized Express*** - The principles of electricity and magnetism are covered as the basis for designing and building MagLev Vehicles.

Assessment

We have received extensive positive feedback from both teachers and students. The good news is that they keep inviting us back. The bad news is that we get many more requests to visit schools than we can handle. So we are looking for ways to package and disseminate ETKs so teachers can use them without direct input from us.

However, the teachers report the greatest benefit to their students is having our engineering students in the classroom. When a team with women and minority students arrives to teach about engineering, the middle school students are excited and inspired. Our local schools have indicated that they want this element of our program continued.

We have started to assess our program and products in more formal ways. The first attempts to evaluate selected ETKs are reported in two recent papers. [4, 5] Chris Schnittka is pursuing a PhD in Science Education, and her research will include formal assessments of these instructional materials.

ETK packaging and distribution

Our ETKs were originally structured for print media. Teachers have expressed the desire for ETKs in electronic form (CDs, DVDs, and Internet). A major advantage of CDs or DVDs is that we will be able to include image and video files to show the ETKs in use. We have started a systematic review of all existing ETKs. Our goal is to make each ETK complete and readily useable by teachers without our presence. We are incorporating the comments we have received from teachers, and imposing a standard format on all ETKs. Our goal is to have the ten ETKs listed above in final form by the end of this year so we can distribute them on a single CD.

We are not alone!

In this paper, we have described one particular approach to the development and distribution of instructional materials, and one way to conduct outreach to pre - college teachers and students. There are many other efforts – both local and national to bring engineering into K – 12 Education.[6, 7] The American Society for Engineering Education maintains a website through its K – 12 Center to make these efforts and resources available to teachers worldwide. The new ASEE K – 12 Engineering and Pre-College Outreach Division has over 400 members. The ASEE K - 12 Center has conducted workshops for local teachers at each of its recent Conferences.

Acknowledgements

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