Designing Engineering Teaching Kits (ETKs) for Middle School Students

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Abstract

The University of Virginia has undertaken a major project to design, implement, test, and distribute Engineering Teaching Kits (ETKs) for use in middle school science and math courses. A new senior design course sequence for fourth year Mechanical Engineers allowed 30 students to participate in this project. Six ETKs are currently being developed: submersible vehicles, gels and brain perfusion, simple machines, solar car design, design for sustainability, and engineering materials. Each will emphasize the engineering design approach to problem solving. Every team has a faculty advisor from Engineering, a representative from the Education School, and a middle school teacher providing advice and assistance. In this paper, we will review our approach to developing ETKs, and briefly describe each of the ETKs and the assessments we are conducting.

Why should engineering schools address K-12 Education?

The United States faces serious problems in science, engineering, mathematics, and technology education:

- Enrollments in engineering programs have been declining;
- The numbers of women and minority students in engineering are not representative of general population;
- Science and math test scores of US high school students are low with respect to the rest of the industrial world; and
- Most students leave high school with no real understanding of engineering or technology; yet most jobs today require some level of technological literacy.

These facts have aroused concern at all levels of government and business. Senator John Glenn's commission report "*Before it's too late*" has focused attention on the seriousness and scope of these problems, and proposed a set of possible solutions [1]. Congress and several state governments have moved to address these concerns. Several engineering

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professional societies, including ASEE, IEEE, ACM, AIAA, ASME, and ASCE have established boards and committees to address Pre-College Education and encourage involvement of their members in K - 12 activities.

Engineering schools must develop better ways to attract and retain students. One way to attract more students is through outreach to the K-12 community. By targeting students in middle schools, we can make them aware of the nature and practice of engineering, and motivate them to pursue the science and math required to succeed in engineering programs.

The Virginia Middle School Engineering Education Initiative

The Virginia Middle School Engineering Education Initiative (VMSEEI) was designed to address this need. Our goal is to design and implement Engineering Teaching Kits (ETKs) to introduce engineering concepts and methods to students in middle school science and math classes. The four major objectives of VMSEEI are to:

(i.) Show middle school teachers and student teachers how to introduce engineering and technology into their classes using ETKs;
(ii.) Use ETKs to promote awareness and stimulate excitement among middle school students concerning the nature and practice of the engineering profession;
(iii.) Develop in the students an early appreciation for the tradeoffs involved in the practice of engineering, and how engineering decisions impact society and the environment; and
(iv.) Attract women and minority students to engineering, mathematics, and science.

We have received funding to design, fabricate, and test several sets of the ETKs, conduct workshops for middle school science and math teachers, distribute these materials to middle school teachers, and eventually conduct a national conference on Engineering Education in the K-12 Curriculum.

What is unique about an ETK?

Our engineering teaching kits are being modeled and developed along the lines of the well proven, carefully evaluated and highly successful science kits developed by the SEPUP program for enhancing science instruction nationwide in the middle schools. The SEPUP kits enhance science instruction by focusing on scientific issues with significant social and/or environmental impact [2].

ETKs will involve topics from science and technology that have interesting engineering applications. We will build on and complement the science and mathematics curriculum in order to advance the engineering design approach to problem solving. Design is the essence of engineering. Although engineers engage in various other activities, it is the design activity that sets them apart from other professionals, such as physicists or chemists. The engineering design process includes at least 5 steps [3]: (a) problem definition, (b) invention, (c) analysis, (d) decision, and (e) implementation. Middle school students will learn about the essential engineering functions: design, build, analyze, test, and measure. ETKs will also include real-world constraints: budget, cost, time, risk, reliability, safety; and meeting customer needs and demands.

Each ETK will include a *student guide* explaining key concepts and methods, a *teacher's guide*, plans for demonstrations and experiments, and, where appropriate, a computer-based component (a simulation or demonstration). Most ETKs will include a design component; some will involve a contest or competition. The ETKs will conform to a standard format, and undergo a uniform set of tests and evaluations. Our goal is to develop, test, evaluate, and distribute six to ten distinct ETKs during the next three years.

ETKs are being designed according to the best pedagogical principles [4,5]. They will involve active, cooperative learning. The students will work in teams to solve problems and design products. The middle school students will reflect on what they have learned, and explore the impacts or consequences of technology. These materials will promote social, ethical, aesthetic, and environmental awareness. Finally, ETKs will promote the development of communication and presentation skills among middle school students, including information gathering and evaluation, data analysis and representation, reporting and documenting observations and results, and assessing assumptions and preconceptions.

Organizational Structure

VMSEEI includes faculty from the Department of Mechanical and Aerospace Engineering and the Curry School of Education at the University of Virginia. Twenty-four undergraduate students have been involved with VMSEEI since September of 2002; six other students joined in January 2003. Additional faculty members are also becoming active. Middle school teachers from Charlottesville and Albemarle County have volunteered their classes as test sites for ETKs. One of our participants, Christine Schnittka, is an engineering graduate of the University of Virginia, and teaches at the Village School - a private school for girls from 5th to 8th grade (ages 10-13). She won the 1999 Virginia Piedmont Technology Council award for excellence in Science and Technology teaching.

Important additional partners are Herbert D. Thier of the Science Education for Public Understanding Program (SEPUP) program and Chris Rogers, Ioannis Miaoulis and Martha Cyr of the Center for Engineering Educational Outreach (CEEO) at Tufts.

"The SEPUP approach to science teaching involves activities and investigations, discussions and debates, and themes and questions. Learners experience the relation of science and technology to social issues as they gather and evaluate scientific evidence, assess risks and benefits, ask questions, and make decisions based on evidence rather than emotion." [6]

The Center for Engineering Educational Outreach (CEEO) at Tufts University brings engineering design projects into the K-12 classroom [7]. Teams of engineering and education experts collaborate with K-12 teachers to design curricula based on engineering programs. Pre-college teachers from the U.S. and abroad have worked with the center to develop materials and curricula, explore new ways to teach, and understand how kids learn. In particular, the CEEO program at Tufts has been instrumental in leading the state of Massachusetts to introduce engineering into the K-12 curriculum.

A key lesson from the SEPUP and CEEO programs is the necessity for long-term commitment to educational reform in order to make a real difference. Both programs have been in place for many years, and both have enjoyed strong leadership. Since we intend for the VMSEEI program to have a major effect on middle school education, we must plan now for its long-term viability.

Initial ETK Development Activities

Five undergraduate students worked with us during the start-up phase of this project. Corey Byrne developed a prototype ETK based on **Solar Power Generation** and how it is affected by the properties of light. Joseph Van Tassel developed activities based on the **design of water rockets**, and incorporated safety and environmental issues into his ETK. Kurt Posner assessed the implications of the Virginia Standards of Learning [8,9] and their relation to National Standards such as those of the National Academy of Sciences [10] and the American Association for the Advancement of Science [11]. Kurt also conducted an informal survey of participants at the 2001 meeting of the Virginia Association of Science Teachers (VAST). Based on their input, he developed an initial version of an ETK on **Simple Machines**. Virginia Ferrell explored the role of gender differences and their implications for instructional design. Ginny examined how ETKs can be designed to appeal to middle-school girls, and how to attract more women into engineering. She has employed a **model car design** contest to teach basic concepts of aerodynamics. Another ETK focused on the creative aspects of engineering: **design and invention**. As an undergraduate**,** Evan Edwards designed and prototyped a novel medical device, submitted a patent application, and formed a company with his brother. Evan's ETK was built around innovative thinking and entrepreneurship.

Current ETK Development

Although we are in the early stages of this project, several things have become already apparent. Our undergraduate students are excited by this project, but formal mechanisms are necessary to ensure their deep and continuing involvement. Both course credit and summer employment will help meet these needs. We have introduced a new senior design project course that will allow us to meet many of the ABET EC2000 a-k engineering criteria. We now have six teams working on ETKs. The descriptions below are based on the mission statements from the teams working on each project.

Simple machines. Kurt Posner developed a preliminary set of exercises to explore simple machines. This semester, Joseph Vargas led a team to fully develop this ETK. Their lesson is a set of interrelated experiments involving simple machines (levers, pulleys, inclined plane, wheel and axle). The goal is to introduce general physics and design concepts. The instructional basis of the ETK will be engineering principles such as force balances, mechanical advantage, and conservation of energy. When the students understand the functions of simple machines, they will execute a series of design projects that use this knowledge. After completing their work on simple machines, this team will move onto more complex machines.

Solar car design This module will build on the work of Virginia Farrell and Corey Byrne. Using predetermined supplies, teams will design and build an electric model car powered by energy derived from light. Students will learn basic concepts and principles of mechanical and electrical energy including how to measure each and how to relate one to the other. They will also learn the fundamental principles of statics and dynamics (friction, drag, acceleration, constant velocity motion). Based on this knowledge student teams will design cars, assess their performance, and predict their power needs. They will also test solar panels, compare the results to the estimated power needs of their cars, and determine the parameters for the design of their cars. They will modify their designs as needed and build preliminary models. Then they will test to confirm their estimates and to refine the design. The goal is to build a "race-quality" car and compete with other teams.

Brain tumor perfusion: This ETK will introduce students to the biological, chemical, mechanical, and medical aspects of perfusion/infusion brain tumor treatment. Student teams will investigate the nature and treatment for this type of tumor, and devise a treatment plan based on their research. Physical models of the brain and the use of a mechanical syringe will simulate the treatment (by infusing colored fluids into a gel). The students will analyze the resulting data and visualize the results. They then assess the success or failure of the treatment. This ETK will also cover the social, cultural and personal impacts of this disease.

Design for sustainability: This ETK is focused on sustainability as an essential consideration in design. The materials will explore the life cycle of everyday objects (such as a cereal box), and examine the production processes and the eventual disposal of the product. The ETK will lead students to address a variety of issues, and assess the potential for redesign, recycling, and reuse. What is a cereal box composed of? Which manufacturing processes are involved in its production? What waste and pollution are associated with producing a cereal box? What happens to the box after it is empty? After they understand the concept of sustainability, teams of middle school students will explore new design concepts for cereal boxes.

Engineering Materials: Our newest team consists of five students recruited by Ioannis Chasiotis from his third year materials class. These students are just getting started, but their ETK will involve engineering materials. Ioannis will serve as faculty advisor for this team and they will continue work on their ETK throughout next year.

Submersible vehicles: This team has developed lesson plans to introduce the concepts of density, mass, volume, buoyancy, drag propulsion, and materials. Students will initially experiment with different objects to determine why they float or sink. They will then explore the concepts of buoyant force, drag, and propulsion. Finally, given a variety of materials and components, teams of middle school students will design their own underwater vehicles. Each group will separately test their final vehicle and evaluate its performance. They will document how each concept in the lesson plans influenced the design of their submarine. This team "Under Pressure" has just spent a week testing their materials in a Charlottesville Middle School. Their ETK, and its design challenge, was very well received by both students and teachers. Extensive analysis of their experience will appear in a future paper.

Transforming projects into ETKs

Under Pressure was our first team to test their materials in an actual school setting. They visited two science classes at Walker Upper Elementary School in Charlottesville. The entire team participated in the trial of their ETK. The lesson plans included team activities and individual assessments. Two students from the Curry School helped develop the final materials for the class. Xeroxed handouts were used to provide the worksheets to the students. The activities included authentic embedded assessments for both teams and individuals. The teachers were asked for their comments on this ETK. And finally team members and an education graduate student observed the class. These inputs are currently shaping the final draft of this ETK.

Evaluation and Field-testing

These ETKs will undergo several stages of testing and evaluation. At each stage of development of an ETK, it will be reviewed and critiqued by Education and Engineering faculty members, students, and middle-school teachers. When the middle school teachers think it is ready, the ETK will be tried with middle school students – either in the classroom or a less formal environment. The reactions of these students to the ETK will be obtained – both through observing the students using it and asking them for their opinions. Do the ETKs hold the student's interest? Are they exciting? And are the students learning what the ETK was designed to teach?

Several ETKs are being tested in middle school classrooms this semester. Two Curry School of Education students are critiquing all of the teams' lesson plans before we use them with the middle school students. Additional testing will occur over the summer with several groups of middle school students visiting the University of Virginia.

Dissemination of Materials and Activities

As the ETKs near completion, we will institute a formal production process. The ETKs will conform to a standard format, and will have similar packaging, design, and layout. Distribution will most likely be printed modules, although electronic means will also be explored. Once the production formats are decided, we can try to upgrade existing materials develop additional ETKs.

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