THE VIRGINIA MIDDLE SCHOOL ENGINEERING EDUCATION INITIATIVE: USING A SENIOR DESIGN COURSE TO DEVELOP ENGINEERING TEACHING KITS

Amanda Kraines, Kelly L. Klanian, Leyf Peirce, Elizabeth Waters, Kristina Gluchowski, Kristopher Janezic, Joshua Labrie, Jennifer Cunningham, Hilary Bart-Smith, and Larry G. Richards

Abstract - At the University of Virginia, we have undertaken a major project to design, implement, test, and distribute Engineering Teaching Kits (ETKs) for use in middle school science and math courses. Each ETK will emphasize the engineering design approach to problem solving. A new senior design sequence for fourth year Mechanical Engineers allowed nearly 30 students to participate in this project. Six ETKs are under development: submersible vehicles, gels and brain perfusion, simple machines, solar car design, design for sustainability, and engineering materials. In this paper, we will review our approach to developing ETKs, briefly describe each of the ETKs, and assess the efficacy of a senior design course for developing instructional materials for middle schools. Under Pressure - the first team to pilot their ETK at a middle school - is featured, and their lesson plans are described along with their assessment methods.

Index Terms – Engineering Teaching Kits, K – 12 Education, Submersible Vehicles, Engineering Design.

The Virginia Middle School Engineering Education Initiative

The Virginia Middle School Engineering Education Initiative (VMSEEI) was established to design and implement Engineering Teaching Kits (ETKs). These kits will be used 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 will 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 – both locally and nationally, 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 highly successful science kits developed by the SEUP program for enhancing science instruction nationwide in the middle schools. The SEUP kits enhance science instruction by focusing on scientific issues with significant social and environmental impact [1]. ETKs will involve topics from science and technology that have interesting engineering applications. They 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 five steps [2]:

1. Amanda Kraines, University of Virginia, Mechanical Engineering, ajk3k@virginia.edu
2. Kelly Klanian, University of Virginia, Mechanical Engineering, klk4n@virginia.edu
3. Leyf Peirce, University of Virginia, Mechanical Engineering, alp2j@cms.mail.virginia.edu
4. Elizabeth Waters, University of Virginia, Mechanical Engineering, eaw5p@virginia.edu
5. Kristina Gluchowski, University of Virginia, Mechanical Engineering, krg4z@virginia.edu
6. Kristopher Janezic, University of Virginia, Mechanical Engineering, ksj3n@virginia.edu
7. Joshua Labrie, University of Virginia, Curry School of Education, jdl8g@virginia.edu
8. Jennifer Cunningham, University of Virginia, Curry School of Education, jlc7d@virginia.edu
9. Hilary Bart-Smith, University of Virginia, Mechanical Engineering, hilary@virginia.edu
10. Larry G. Richards, University of Virginia, Mechanical Engineering, lgr@virginia.edu
(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 redesign. Each ETK will also include real-world constraints: budget, cost, time, risk, reliability, safety, and meeting customer needs and demands. As the students are exposed to the engineering process, they will also actively apply what they are learning along with their own creativity to complete a design project.

The kits 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). All 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 [3,4]. 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 to explore the impacts and 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.

A NEW SENIOR DESIGN COURSE: THE DESIGN AND IMPLEMENTATION OF ENGINEERING TEACHING KITS

In the fall semester of 2002, the Department of Mechanical and Aerospace Engineering at the University of Virginia introduced a new senior design experience. This design project course will allow us to meet many of the ABET EC2000 a-k engineering criteria. Six student teams are now working on ETKs.

Simple machines. The goal of this project is to introduce general physics and design concepts involving simple machines (levers, pulleys, inclined plane, wheel and axle). 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 apply this knowledge.

Solar car design. Using predetermined supplies, student 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. Testing will be carried out 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: Students will be introduced to the biological, chemical, mechanical, and medical aspects of perfusion/infusion brain tumor treatment. Each team 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 will 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 lessons 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 is in the process of developing an ETK that will introduce students to engineering materials – both traditional and revolutionary. Ioannis Chasiotis recruited this team from his third year materials class. They will describe properties and applications of materials and how they are used in engineering design. Ioannis will serve as faculty advisor for this team and they will continue work on their ETK throughout next year.

UNDER PRESSURE: DEVELOPING AN ETK ON SUBMERSIBLE VEHICLES

We will focus on Under Pressure as the prototype ETK development team. This team has developed lesson plans to introduce the concepts of density, mass, volume, buoyancy, drag propulsion, and the role of engineering materials. Middle school students initially experiment with different objects to determine why they float or sink. They then
explore the concepts of buoyant force, drag, and propulsion. Building upon this knowledge base, the middle school students are asked to design and build their own underwater vehicle using a variety of materials and components available to them. This task is performed within a team environment. Each group separately tests their final vehicle and evaluates its performance. They are asked to document how each concept in the lesson plans influenced the design of their submarine.

**Under Pressure** consists of Beth Waters, Amanda Kraines, Kelly Klanian, Kris Janezic, Leyf Peirce, and Krissy Gluchowski. Arlene Terrell (far left) teaches at Walker Upper Elementary School and Hilary Bart-Smith (far right) served as the faculty advisor for this team. This team recently spent a week testing their materials in a Charlottesville middle school. The ETK was very well received by both students and teachers. Extensive analysis of their experience will appear in a future paper.

**Under Pressure** was our first team to test their materials in an actual school setting. They worked with two science classes at Walker Upper Elementary School in Charlottesville prior to and during the trial of their ETK. The lesson plans included team activities and individual assessments. Two students from the Curry School (Jennifer Cunningham and Josh Labrie) helped develop the final materials for the class. Worksheets were provided to the students. The activities included authentic embedded assessments for both teams and individuals. The teachers were asked for their comments on this ETK. Team members and an education graduate student observed the class. These inputs are currently shaping the final draft of this ETK.

**Materials and Supplies**

The first challenge was to find a large tank in which to test the submersible vehicles. The team had one custom built. The tank was constructed of 3/16” thick aluminum; its dimensions were 60”x22”x22”. The front was a clear 1/2” plexiglass sheet sealed with a rubber gasket and attached with bolts and locking washers. Student teams could observe their vehicles from above and in front.

For building the submarines the students used plastic water bottles, and commercially available submersible motors. They also had assorted materials available: sand, rice, marbles, washers, foam, cork, beads, screws, and whatever the kids found that seemed useful to them—this created an emotional attachment to their design. Other items were needed for some experiments: buckets of water, honey, graduated cylinders, spring scales, string, straws, and balloons.

**Preparation**

The **Under Pressure** team developed an initial lesson plan that was critically reviewed by both middle school teachers and graduate students from the Curry School. Everything from materials to logistics to student handouts was evaluated. The team tested all their planned activities themselves before using them in class. They met to conduct a trial run of each day’s activities during the week prior to going into the class. When necessary, they revised the activities to meet time requirements. All the materials were collected, assembled, and checked in advance, including all lesson plans and worksheets.

Two science classes were involved in this initial test of an ETK - one met at 8 a.m. and the other at 10. The middle school students were assigned to teams of 4-5 students each. The teachers made up the teams based on their knowledge of the students and the dynamics of the classroom.

**Five Lessons**

**Day 1: Density.** As the Lesson started, students were asked to predict what would happen when two Coke cans were placed in the tank – one was a regular Coke, the other a Diet Coke. Students were then asked to support their predictions. The Diet Coke floated, the regular Coke sank to the bottom of the tank. They were asked why one floats and the other sinks to the bottom? The students were introduced to the concepts of mass, volume, and density. They learned how to find mass and volume in order to calculate density. As a class the groups shared their results, and compared their calculated densities with other groups’ and to the density of water. Students were able to discuss why their calculated densities varied among groups, and how they could be more accurate if they were to repeat the experiment. Each team completed a lab exercise and recorded their results. Each student also completed a set of discussion questions.

**Day 2: Buoyant force, drag, propulsion.** This class explored the forces acting on an object moving through water. There were three student workstations—one devoted to drag, the second to propulsion, and the third to buoyant force. Teams of 5-7 students spent 12 minutes at each station. Buoyant force was illustrated by the apparent loss of weight when an object is submerged. Students used spring scales to measure the loss of weight produced by fresh water and saltwater. This loss of weight was explained to the students using buoyancy.
Drag was illustrated by how the orientation of an object in a fluid affects the forces acting on the object. The students timed the movement of washers through honey. The orientation of the washer was either flat or upright. Propulsion was explained in terms of Newton’s Laws, with special emphasis on the Third Law. It was demonstrated using a balloon attached to a straw moving along a string – propelled by the escaping air.

Day 3 and 4: Design and Construction of Underwater Vehicles. The students were introduced to the engineering design process, and were presented with their problem and basic submarine components (a motor and water bottle). One handout described the engineering design process, and another led the students through some initial planning. By applying the knowledge gained during the previous lessons, each team calculated the mass and volume necessary to make a submersible vehicle neutrally buoyant. They then started to design and build their vehicles. A variety of materials were available, and no constraints were placed on how these materials could be used.

Day 5: Final competition: On the final day, the teams demonstrated the capabilities of their vehicles. They placed their submarine in the tank and directed it toward a set of submerged rings. Success was defined by: (1) the submarine being neutrally buoyant, and (2) its ability to pass through the submerged rings. The submarine should stay at the depth it was placed, and then propel itself through the rings.

After the first trial each team could adjust their design and then try again. At the end of the session the entire class discussed what worked, and what did not. The teacher emphasized the need to redesign when things didn’t work.

TEAM REFLECTIONS: WHAT DID UNDER PRESSURE LEARN FROM THIS EXPERIENCE?

- They have a winning project. The students and teachers were enthusiastic, interested and involved.
- The team felt that there should be greater emphasis on engineering, and that VMSEEI should promote a uniform engineering design process for all ETKs.

Creating the Product: Transforming Projects into ETKs

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, an 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. For example, do the ETKs hold the student’s interest? Are they exciting? Are the students learning what Engineering should be the central focus of each ETK. Currently, a day is being added at the beginning of the entire unit to introduce students to the engineering design process and different fields of engineering.

- Time constraints are severe. You can only do so much. Each lesson was modified to fit into the limited time available.
- Under Pressure had up to eight people available to help during this trial of their ETK. A single teacher, or perhaps a couple of people in the classroom will eventually use it. How can the ETK be structured for use in this situation? Is one teacher enough? Given more time for the unit, yes.
- Group dynamics are important. The teachers know their students; only they can put together compatible groups.
- To reinforce the engineering design approach middle school students should be introduced to several ETKs. This option is currently being explored with the help of teachers at local schools.
the ETK was designed to teach? Does the ETK teach the science content effectively? What do the students learn about engineering?

Several ETKs are being tested in middle school classrooms this semester. Significant insights have been gained from the team’s interactions with the graduate students from the Curry School. They are critiquing all of the 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 final ETK formats are decided, we can try to upgrade existing materials and develop additional ETKs.

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**REFERENCES**


