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Getting Them Early: Teaching Engineering Design in Middle Schools*

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At the University of Virginia, we have undertaken a major project to design, implement, test and distribute Engineering Teaching Kits (ETKs). These kits introduce engineering concepts and methods into existing middle school science and maths classes. Students learn about essential engineering functions such as how to design, build, analyse, test and redesign. ETKs promote awareness of the nature of engineering and stimulate excitement about its practice. Twenty-two ETKs have been field tested in local middle schools.

Keywords: K–12 engineering education; pre-college outreach; engineering design; engineering teaching kits; middle school science and maths

INTRODUCTION

Challenging times for engineering education

AT A TIME WHEN technology permeates our lives, too few US students pursue degrees in engineering. Enrolment of US students in engineering has been declining nationally for more than a decade and graduate degree programmes in science and engineering are now dominated by students from other countries [1]. Previously, such students would stay in the United States after finishing their degrees. Now many return to their home countries after graduating. Thus we are not replenishing the talent pool that will ensure a steady stream of innovations from American industry and research labs.

Technological illiteracy is widespread: most people have little understanding of the technologies they use in everyday life. In particular, legislators and policy makers often do not understand the technologies they must fund and regulate [2].

In colleges of engineering, women and minorities are vastly underrepresented—both as students and faculty. Nationally fewer than 20% of engineering students are women.

In the early grades, girls perform as well as, or better than, boys in science and maths. But in middle school, many girls lose interest in technical subjects.

Middle school is a critical transition period. It is where decisions are made that will open or close career options. Maths and science are the keys to careers in engineering and technology. If students decide not to pursue these subjects in high school, they are essentially closing the doors to certain professions. Thus our main challenge is attracting middle school students to science and engineering.

Engineering schools and professional organizations are now reaching out to K–12 students and teachers to convey the nature and excitement of engineering. We are trying to motivate students to stick with the subjects (maths and science) that provide the basis for exciting technical careers. In an influential report from the National Academy of Engineering, the case is made for bringing engineering and technology into K–12 Education [2]. The American Society for Engineering Education has a new Division on K–12 Engineering and Pre-College Outreach [3], and a Centre for K–12 Engineering Education [4]. The Commonwealth of Massachusetts has introduced a Curriculum Framework that includes engineering, design and technology as central components of K–12 Education [5].

Our project

The Virginia Middle School Engineering Education Initiative (VMSEEI) was established in 2001. Our main mission is to design, implement, test and evaluate Engineering Teaching Kits [6]. These ETKs help teachers instruct middle school students about engineering concepts and procedures within the context of existing science and maths courses. ETKs involve active, hands-on learning; students work in teams to solve problems and design solutions. ETKs focus on design and innovation, how (and why) things work, how things are made and the social and environmental impacts of technology.

Each ETK emphasizes the engineering design approach to problem solving. We identify topics from science, maths and technology that have interesting engineering applications and then design kits that help students learn science and

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maths in the context of engineering design. Each ETK involves a design challenge requiring creativity and teamwork as students consider real-world variables such as a budget, time management, risk assessment, product reliability and safety and customer needs and demands.

ETK DEVELOPMENT

In our first year, five individual 4th year engineering students tried to develop ETKs for their senior thesis projects. All developed reasonable first drafts of lesson plans, but were not able to carry through with teacher evaluation and classroom testing. We decided that teams of students were required to realize all the tasks necessary to develop an effective ETK.

Since 2001, we have offered a senior design course in Mechanical Engineering (MAE 491D/ 492D) focused on developing engineering teaching kits (ETKs). Teams of fourth year students design, implement and test ETKs. This course runs for two semesters and requires each team to develop an ETK and use it in at least one local middle school. Most teams have faculty advisors and all work with graduate students from the Curry School of Education as well as local middle school teachers.

The course covers all the usual material related to the engineering design process, but also includes the psychology of learning, principles of instructional design and assessment and evaluation techniques. These additional topics are necessary because we develop instructional materials for middle schools, but few engineering students have taken the appropriate courses in psychology and education.

PEDAGOGY

Our engineering teaching kits embody the pedagogical technique *Guided Inquiry* [7], and reflect the latest knowledge about how people learn [8, 9]. While we carefully plan the concepts, methods and skills we want the students to master in the ETK, inquiry is the process through which they truly learn. What makes a lesson inquiry-based is the fact that students are collecting data and answering a question, whether posed by themselves or the teacher. 'How can I get this motor to pull the most weight?' 'How can I get this bridge to hold a truck full of bricks?' With guided inquiry, students are given the materials and tools they need to succeed without the cookbook-type procedural lessons most commonly seen in middle school science classes. These concepts and skills are tied to the Virginia Standards of Learning [10], the Massachusetts Curriculum Framework [5] and National Science Standards [11, 12, 13]. All ETKs involve active, cooperative learning. Students engage in hands-on problem solving while working in teams.

The essential component of all ETKs is an engineering design challenge that requires the teams of middle school students to use the concepts and skills they have learned to realize an integrated solution to the problem. Every ETK starts with a discussion of the nature of engineering and a description of the engineering design process.

In their lessons, middle school students conduct experiments and systematic investigations, use measuring instruments, carefully observe the results, gather, summarize and display the data, build physical models and analyse costs and tradeoffs.

At the end, they reflect on their experiences and the results of the design competition. Each ETK is initially designed for five 50-minute lessons. However, flexibility is necessary because different schools have block schedules and some teachers are able to spend more time on each kit.

The kits are designed to be used in existing science or maths classes. Engineering design can be a vehicle for teaching science and maths concepts; it is our hypothesis that students will learn maths and science concepts better when they have practical applications for them [14, 15]. Humans evolved to be problem solvers; technology is the precursor to both maths and science in civilization. Hence, coupling technological design challenges with the maths and science just may make better pedagogical sense.

In general, our approach to assessment is to embed realistic tasks within the ETKs rather than focus on external 'tests' [7]. Just as in the real world of engineering, the teams demonstrate their understanding of concepts by using them in their experiments and design. However, we have recently conducted some formal testing to establish the effectiveness of the ETKs, and show that they help to develop the kinds of knowledge required for standardized tests [16]. Our purpose was to assess the effectiveness of the ETKs and find ways to improve them. We were not interested in evaluating the performance of individual students.

PRODUCTS

What do engineers do? Every ETK starts with a discussion of the nature of engineering and science. Many students do not understand that there are critical differences between these domains. Through a series of exercises, we lead the middle school students to appreciate the different perspectives, methods and approaches to problems taken by engineers and scientists. Our goal is for them to understand the engineering design process and its various stages. This lesson is now the standard introduction to all ETKs.

Engineering is more focused on the design and production of technology. Design is the essence of engineering, distinguishing it from the sciences. In many ways, this unique approach to problem solving is opposed to the usual teaching structure.

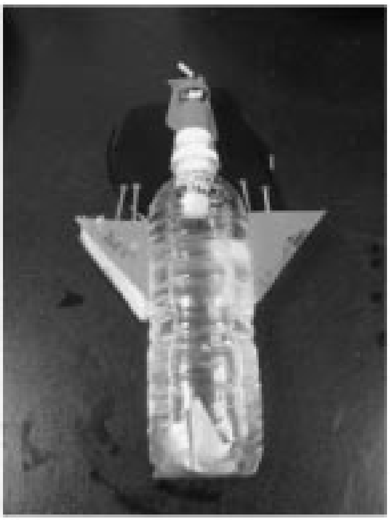

Fig. 1. Submersible vehicle.

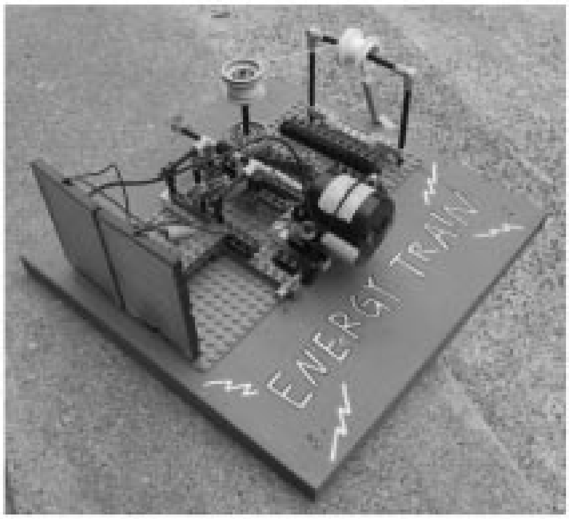

Fig. 2. The Energy Train.

In place of one single best answer to a problem, there are many practical solutions. Given a design problem, the initial task is to generate as many solutions as possible, then select a concept to pursue based on feasibility and other criteria. A prototype is constructed and the idea is evaluated. If a concept does not work out as planned, it may be redesigned, modified, or scrapped. If a design meets our requirements, it can still be improved.

Initial ETKs—the first wave

In the first year of our course, three successful ETKs were produced: submersible vehicles, model solar cars and brain tumour treatment technologies. In this paper, we highlight two of these ETKs and three from later years.

*Under pressur*e

Our first successful ETK focuses on submersible vehicles. The lessons cover density, buoyant force, drag and propulsion. Each requires experimentation and data analysis. The design challenge is presented in two parts: first each team must make an ordinary plastic bottle neutrally buoyant so that it floats halfway down in a tank of water. After students achieve this goal, a motor is glued to the bottle and the team must figure out how to make their submarine move across the tank through a series of hoops.

Hilary Bart-Smith, Assistant Professor of Mechanical and Aerospace Engineering, was the faculty advisor for this team. This ETK is described in detail in a paper co-authored by Bart-Smith [17].

Figure 1 shows an example of the final product from a middle school design team. The bottle is filled with sand and water. After the motor was attached, the students added external features (fins, weights) to improve the aerodynamics of the vehicle.

Since this was the first ETK actually used in a middle school, it has been extensively studied. The team was very good at documenting their procedures and reflecting on their experiences. They taught two classes at a local middle school; one at 8 a.m. and the other at 10 a.m. During the hour between classes the team reflected on the first session and made changes for the second class as a result. They revised their final version of the ETK to include greater emphasis on engineering and a uniform model for the engineering design process.

RaPower

This ETK is about energy and energy conversion. It starts with a demonstration developed and built by Christine Schnittka. 'The Energy Train' is an electro-mechanical system with several components. Solar cells capture light from the sun and convert it to electrical energy. The electrical energy drives a motor mounted with a series of connecting gears, converting electrical to mechanical energy. The motor pulls a string attached to a cart. The middle school students observe the energy train in action and are asked to explain what is going on. Through a series of questions and guiding responses, the class arrives at an accurate description of how the Energy Train works.

The solar car

Over three class periods, the middle school students conduct experiments to assess the efficiency of three different solar cells, the lifting power of three motors, and the friction of four types of tyre materials. Their design challenge is to use these components to build a solar car that will pull a cart loaded with weights. The team whose car pulls the most overall weight wins.

However, the teams are given a budget and the components are priced so that they cannot afford all of the most effective components. They must make compromises and tradeoffs to achieve their final design. Each team receives a standard LEGO

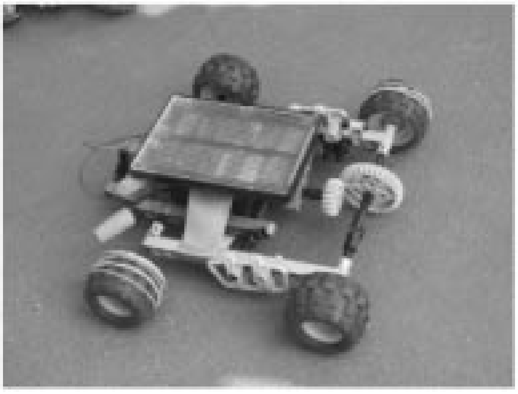

Fig. 3. A solar car designed by middle school students.

car body, and 'purchases' the solar cell, motor and tyres they choose. They build and test their car, and may change the design as they progress. We allow teams to modify their design even during the final competition. After a winner emerges, the class reflects on the results, analyses what worked, what did not and why, and suggests ways to make the final designs even better.

Gabriel Laufer, Associate Professor of Mechanical Engineering, was the faculty advisor for the *Ra Power* team. *Ra Power* has been the most frequently used ETK and is very popular with teachers and students. It has been successfully implemented with children as young as the second grade (with extensive help and direction) and with high school juniors and seniors (with no help and little direction). It has been used extensively with middle and high school classes, workshops, and summer programmes.

Catapults in action

In our second year, this was the most successful ETK. It was developed in response to middle school teachers' requests for a unit on projectile motion. The ETK starts with a brief history of catapults and trebuchets, and their use in warfare. The engineering concepts introduced in this ETK include energy principles, kinetic and potential energy, spring constants, simple machines—especially the three classes of levers—and projectile motion. The design challenge is to build and test a catapult that can be adjusted for distance and accuracy. In the final competition, a medieval castle is located at one end of a large room—with a launch station at the other end. Each team configures and tests their catapult. Two tests are required: one is to toss the payload over the wall and as far into the castle as possible (distance); the other is to hit a turret on the side of the castle (accuracy).

After our team taught this ETK to two groups of maths students in a local middle school, the teachers asked us to leave the materials with them. These maths and science teachers joined with colleagues from history and literature and taught this ETK as a unit that integrated all these subjects. They taught eight additional classes using this integrated approach.

Aerospace engineering

Also during the second year of VMSEEI, engineering student Ashley Hallock developed an ETK that encompassed both aerodynamics and rocketry. She was the sole aerospace engineering student in the class and worked alone on her ETK. Her lessons covered concepts related to airplanes: forces, pressure and how these contribute to flight; lift, drag, thrust and weight; action-reaction forces and Newton's third law, momentum, Bernoulli's equation and the theory of lift and the Coanda effect. She also introduced speed, velocity and acceleration. Students tested different control surfaces (rudders, ailerons, elevators) and their effects on flight via active experimentation. They had to determine how to control the flight path of a balsa wood glider.

For rockets, many of the same concepts were involved. Here the goal was to design and build a working model rocket from common household materials: Fuji film canisters with vinegar and baking soda, or water and alkaseltzer, as the propellant.

For the design challenge, students were divided into three plane teams and three rocket teams. The aircraft teams were tasked with flying their gliders along a path that would avoid the rockets; and the rocket teams tried to intercept the planes.

Get stressed

In the third year, another very successful ETK was created. It focuses on structures and bridges and introduces the different types of bridges used throughout history. The engineering concepts include tension, compression, normal and shear stresses, and material properties. Specific lessons demonstrate tension and compression (with string cheese), stress and strain, plastic and elastic deformation and the difference between ductile and brittle materials. The design competition is to build the strongest bridge, given a choice of structure types and everyday materials but constrained by costs and a budget. The bridge that supports the heaviest vehicle is the winner.

RESULTS

Over the five years of VMSEEI, we have field-tested ETKs in both formal and informal educational settings. During the school year, we work primarily with middle school classes during their normal class hours. Over the summers, we have worked with the Summer Enrichment Programme (SEP) at the Curry School of Education, and an Introduction to Engineering Summer Programme at the University of Virginia's School of Engineering and Applied Science.

In the first four years of the senior design course, we have developed twenty-two successful ETKs.

Six graduate students from Education have been involved in VMSEEI. We have visited 21 middle schools, worked with over 30 middle school teachers, and reached over 1500 middle school students. At least 10 engineering students involved with VMSEEI have become teachers, and of course all the Curry School students have.

Performance of the class (MAE 491D/492D)

Table 1 lists examples of successful Engineering Teaching Kits. All of these ETKs have been field-tested in middle school science and/or math classes. We have been successful in developing instructional materials in this senior design course. Mechanical engineering undergraduates, with the help of teachers and education graduate students, can produce exciting and instructionally sound engineering teaching kits.

The five ETKs highlighted in the previous section are those for which we present data in this paper.

Table 2 below shows ETK productivity for the first four years of this course. In the first year, five teams undertook projects to develop ETKs. All had reasonable lesson plans by the end of the year, but only three had tested their lesson plans in middle school classes. In the second year, six additional ETKs were developed, but only five teams actually tested their ETKs in local middle schools. However, one of these teams discovered that their design challenge was not compelling for the middle school students. In year 3, of seven design teams, five ETKs were tested in local middle schools. Last year, six teams attempted to develop ETKs; only three were completely successful.

Why do some teams fail, and others succeed? Three primary factors seem to be involved: team dynamics and motivation, membership changes within the team and technical or cost issues. In the first year, a couple of teams never developed the project management skills to get everything done. One team worked very well during the first semester, but when a key member graduated, no one assumed leadership of the team and their performance deteriorated. Last year, the Fuel Cell team had reasonable lesson plans and an interesting design challenge, but the cost per kit for their materials was more than £125 per team. In addition, the team of fourth year undergraduates had to work for several weeks to assemble and adjust the components of the fuel cell car so it worked correctly. We had to conclude that this kit was not ready for use in middle schools.

To address the issues of team functioning, we

Table 1. Examples of Engineering Teaching Kits

ETK	Topics	Design Challenge
Under Pressure	Submersible Vehicles	Build a submarine that is neutrally buoyant and can be propelled through a series of hoops in a tank of water.
Ra Power	Model Solar Cars	Using selected components, build a solar car that will pull a cart loaded with weights.
Brainiacs	Brain Surgery Fluid flow	Develop a device or system to deliver an exact amount of a drug to a particular location in the brain
Destructural Mechanics	Materials, composites and methods for reinforcing structures	Build a simple beam that can support a heavy load, using available materials and means of reinforcing it.
Pump It Up	Artificial Heart Pumps	Design and build a functioning heart pump.
Catapults in Action	Projectile Motion	Build a catapult to toss a projectile the maximum distance, and then to accurately hit a target
Alternative Energy Resources	Wind power	Build windmills to generate electricity to power a machine
Aerospace Engineering	Planes and rockets	Pairs of teams compete: one builds a plane that will fly a given course, and the other builds a rocket to shoot it down.
Losing Stability	Floating stable structures	Construct a floating platform and structure to retain a balanced ball during wave motion
No Batteries Required	Fuel cell technology	Construct a working model of a fuel cell car
Aspects of the Crash	Motor Sports	Build a passenger safety system that will protect an egg during a crash test.
Bio Mech- A- Tek	Artificial arms Invention for Accessibility	Invent devices that replace functions of the arm
Get Stressed	Building bridges	Build the strongest bridge, given a choice of designs and everyday materials but constrained by a budget.
Crane Corp	Simple machines	Build a functioning crane to maximize the lifting capacity of the final structure
The Real Green Team	Sustainable House Design	Design and construct a model house that is energy efficient and environmentally friendly
Filtering Ideas	Water filtration	Design and build a system for removing particles and contaminants from water.
Crash and Burn	Crashworthy Vehicles	Build a vehicle capable of flying off a ramp without damage.
HoverHoos	Hovercrafts	Design and build a hovercraft that travels a straight path.

Table 2. Success rates for teams developing ETKs

Academic Year	Number of teams	Number with acceptable lesson plans	Number with acceptable design challenges	Number of ETKs tested in middle schools
2002–2003	5	5	3	3
2003–2004	6	5	4	5
2004–2005	7	6	5	5
2005–2006	6	6	5	3

added material to the senior class on how groups can become high performing teams and introduced several team-building exercises. In the second and third years, we have seen a noticeable rise in productivity due to these changes.

Effects on undergraduate students

We have visited middle school classes throughout Central Virginia, and participated in summer programmes. The Mechanical Engineering undergraduates have learned about the teaching profession and how to develop instructional materials. They have learned ways that courses and lessons are designed; with teaching being the 'royal road to learning', it has actually reinforced their own facility with science and engineering concepts.

Observations from middle school teachers

The middle school teachers concur with our observations that their students are highly motivated during the ETKs. They indicate that with the ETKs, students exhibit few behavioural and attention problems and they seem to learn the material with little effort. The teachers have also noted the importance of our students as role models. When our female engineering students come into a classroom, the middle school girls see that they too can become engineers. Minority students also serve as valuable role models.

We are now regularly invited back to the schools. Indeed, we have more interest than we can accommodate—especially from schools outside our immediate region. Our cohort of teachers has expanded as we have earned enthusiastic advocates for the value of teaching engineering principles to middle school students in their science and math classes.

When we first teach an ETK, a large team of university students and faculty appears in the classroom. That naturally raises the questions: can individual teachers use the ETKs without our help? Can a single teacher use an ETK effectively? Yes! Several teachers have done so, and some have made adaptations of existing ETKs. The most widely used ETKs have been the Solar Car unit, Catapults in Action, Submersible Vehicles and the Brainiacs unit. The Solar Car ETK has been conducted with students ranging from second graders to high school students, in summer programmes as well as regular classes at several schools. The time frame has been as little as one hour to as long as two weeks. One of our former Mechanical Engineering students, Ginger Moored, taught for two years at an inner-city school in Washington, D.C. With no budget, but lots of motivation and ingenuity, she taught the submarine ETK to a ninth grade pre-engineering class. She also taught simple machines. The Brainiacs unit has also been taught in several environments. Thus several ETKs have been successfully used by people other than their development team.

TEACHERS' FORMAL ASSESSMENT OF VMSEEI AND ETKS

The summer of 2003 we convened a Teachers' Workshop at the University of Virginia [18]. Seventeen middle school teachers attended—from the City of Charlottesville, Virginia; the counties of Albemarle, Fluvanna, and Orange; and Richmond, Roanoke, and Washington, D.C. These teachers were given an honorarium for their services. In addition, students and faculty from engineering and education participated, and the entire workshop was observed by a visiting faculty member from Pennsylvania State University (her speciality is programme assessment; she helped assess our project for NSF). The workshop occurred in the summer after the first year of our ETK design course. Thus we had three complete ETKs that had been successfully used in middle schools: *Under Pressure, Ra Power* and *Brainiacs*. At the workshop, each of these ETKs was described in detail—with demonstrations and lab exercises. Then the teachers provided detailed assessments of all three ETKs, and evaluated our overall approach to bringing engineering design into middle schools.

For us the key question was: Does engineering design seem to be a reasonable way to introduce science and maths concepts to your students? All 17 teachers answered 'yes'; 15 unequivocally, and two with proviso—but give us more. Some comments from the teachers:

> 'Creativity and problem solving skills used for engineering design seem like a great "spark" or springboard to sci/math concepts.'

> 'The general "problem solving" of engineering design tasks force the student to understand tough scientific and mathematical concepts in a broad way—as skills for practical application, not fact.'

> 'Learning by discovery and invention are proven to be some of the best ways to learn. Problem solving will help incorporate what students know into what is possible.'

And from those who wanted more:

> 'I would like to see the enhancement of the MATHS applications so kids can see the relation of math with science to an even greater degree.'
>
> 'Most of the ETKs could incorporate math in an applied way that would be incredibly productive to learning.'
>
> 'There are ways to integrate Language Arts/Literature and History as well.'

We asked a series of questions to assess the adequacy and relevance of our materials and approach to the teachers and their classes. The results are summarized in Table 3.

Overall, these results indicate that the ETKs are on target; they cover the key concepts, address the Virginia SOLs, enhance understanding, provide applications and promote problem solving. The low response to some questions for the Brainiacs unit reflects the fact that most of our participating teachers teach physical science, and this unit was developed for classes in the life sciences. In the US sixth and eighth grade science classes address Physical Science and seventh grade science focuses on Life Sciences.

Table 3. Answers to selected questions about ETKs ($n = 17$)

Do you cover the topics of the ETK in your classes?	
Under Pressure (submarines)	9 yes
Ra Power (model solar cars)	13 yes
Brainiacs (brain surgery)	2 yes
Are the lesson plans and student worksheets clear and easily readable?	
Under Pressure (submarines)	14 yes
Ra Power (model solar cars)	12 yes
Brainiacs (brain surgery)	12 yes
Does this ETK adequately address Virginia Standards of Learning (SOL) topics?	
Under Pressure (submarines)	10 yes
Ra Power (model solar cars)	8 yes, 3 uncertain
Brainiacs (brain surgery)	7 yes
How well are the basic science concepts presented in the material leading up to the design project?	
Under Pressure (submarines)	14 very well
Ra Power (model solar cars)	10 very well
Brainiacs (brain surgery)	6 very well
Do you think that your students will come away from the unit with a better understanding of the science content?	
Under Pressure (submarines)	14 yes
Ra Power (model solar cars)	13 yes
Brainiacs (brain surgery)	10 yes
How effectively do you think the design project requires the students to apply what they have learned?	
Under Pressure (submarines)	12 very effectively
Ra Power (model solar cars)	9 very effectively
Brainiacs (brain surgery)	7 very effectively
Does this ETK include sufficient problem solving activities?	
Under Pressure (submarines)	12 yes
Ra Power (model solar cars)	9 yes
Brainiacs (brain surgery)	11 yes
Is the information provided sufficient for you to use this ETK in your classes?	
Under Pressure (submarines)	11 yes
Ra Power (model solar cars)	10 yes
Brainiacs (brain surgery)	8 yes

Packaging and timing of ETKs

How long should an ETK be? Answers ranged from five days to two weeks. In general, our target of five 50-minute lessons seemed about right, but some teachers indicated that more than five days would be okay and ETKs as long as two weeks could be easily integrated into existing science and math classes. Teachers suggested that we should allow adjustability so that the kits could accommodate different grades and ability levels. There could be three versions of each ETK: short (three days), medium (five days) and long (two weeks).

Most teachers wanted access to the ETKs in electronic form (Web Page or CD). But many also wanted print versions, and some indicated that multiple formats were necessary. The teachers were also interested in workshops and institutes, professional development opportunities, and accessible, responsive support (including a frequently asked questions page on our website). Supplementary features should include pre- and posttests, quizzes and rubrics (for embedded assessment), supply lists, and goals and challenges to enhance motivation.

Effects on middle school students

During our classroom experiences we observed high levels of interest, involvement, even excitement among the middle school students. But, do they learn anything? We have gathered some before and after data to address this question. The first formal evaluation study was done by Ashley Hallock for her senior thesis [16], and the second was done in the summer of 2005 with students from a summer enrichment programme.

Hallock (2005) conducted her Aerospace ETK at a local middle school, working with two eighth grade science classes—an honours section and a standard class. She gave all the students two tests, one at the beginning of the first day and one at the end of the last day. The two tests were identical, containing nine questions on the main concepts taught by the ETK. Since the instructor had already taught his usual unit on physics and had reviewed many of the concepts involved in the ETK, the pretest would demonstrate the students' level of prior understanding of the material. Through a comparison with the posttest, she was able to determine exactly how much information the students gained (or lost) by participating in her ETK. Figure 4 shows the pre- and posttest scores for each student in the standard class, and Figure 5 shows the honors class pre- and posttest results. The honours class ($n = 17$) had an initial class average of 19.68 out of 45 and a final class average of 29.14 (a 38.8% increase). The standard class ($n = 17$) had an initial class average of 12.18 out of 45 and a final class average of 23.76 (a 48.8% increase). Female students in the honours class showed a 41.6% increase in test scores, while female students in the standard class showed a 40% increase in test scores.

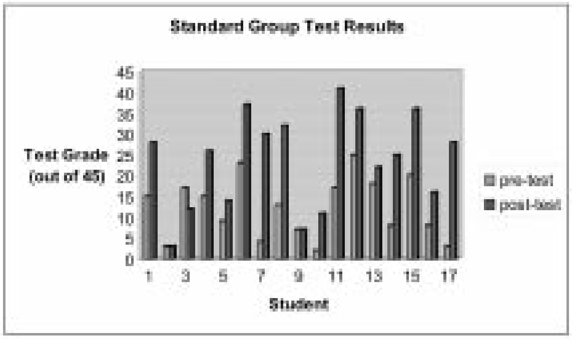

Fig. 4. Standard group test scores for each student: Aerospace ETK

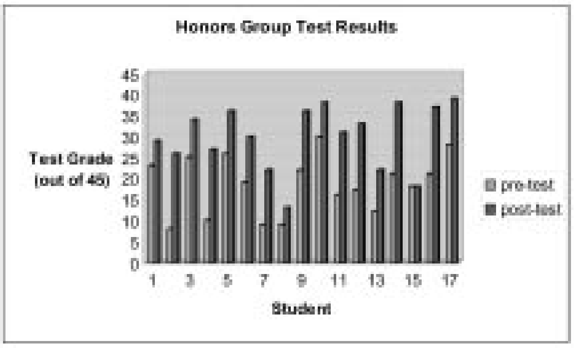

Fig. 5. Honours group test scores for each student: Aerospace ETK

LEARNING RESULTS FROM THE SUMMER ENRICHMENT PROGRAMME

Every year, a Summer Enrichment Programme is conducted by the Curry School of Education for middle school students from Virginia and surrounding states. We have used this programme as a testbed for ETKs for the last three years. This year, Ashley Hallock conducted engineering sessions with six groups of middle school students. Each session lasted two weeks and covered a particular ETK. The ETKs were *Catapults in Action, Get Stressed* (building bridges), *Rockets*, and *Ra Power* (Solar Cars).

These middle school students were bright and highly motivated. They chose to attend a summer enrichment programme, and they selected sessions on engineering rather than art, theatre or creative writing. As a pilot study, we wanted to assess students' gains in understanding of key concepts as a result of participation in the ETKs. Therefore, Hallock administered pre- and posttests on the material covered in each unit.

Figures 6–9 show the mean performance of the four groups on the pre- and posttests for four ETKs. Matched pairs t-tests revealed that all four ETKs resulted in statistically significant improvements in test performance [19, 20].

In all four cases the students arrived with prior knowledge of the concepts involved in the ETK, but made significant learning gains in all four ETKs. The scores along the y-axis differ for these four figures. This is because the number of items, and therefore the maximum score varied for the four tests. The maximum scores for the four tests are solar car = 30, rockets = 40, catapult = 60, and bridges = 75. Matched pair $t = -9.35$, p-value <0.0001 for the solar car; $t = -4.66$, p-value $= 0.001$ for rockets; $t = -12.61$, p-value < 0.0001 for catapults; and $t = -11.14$, p-value < 0.0001 for bridges.

We have not had the opportunity to conduct a long-term follow-up study on students who have participated in ETKs at local middle schools. We have only anecdotal evidence to report. The last two years, we have participated in a seventh grade career fair conducted by a local business group. Over 700 students attend each year. Those students who have experienced our ETKs remember them, and approach us to ask when we are coming into their new schools. We asked what they remembered from the experience and were surprised by how much the students recalled and how accurately they describe the concepts we taught them. Ashley Hallock recently met a freshman girl in the engineering school who remembered her and the class that she taught. The student said that it helped her to choose engineering for her undergraduate major. Such experiences reinforce our activities, but of course systematic data are needed to establish the true value of this programme for attracting students to engineering.

CONCLUSIONS

The Virginia Middle School Engineering Education Initiative (VMSEEI) was undertaken as an experiment. At each stage, we were trying things we had not done before. We wanted to attract middle school students to engineering and technology. Engineering Teaching Kits seemed a reasonable way to start—they could give young students the experience of designing and building something. We decided that undergraduate student teams could develop these ETKs, and learn about the design of instructional materials. Throughout this project, we have collaborated with education school faculty and graduate students to test and improve our ETKs. Our most valuable collaborators have been the middle school teachers who have allowed us into their classrooms and provided us with extensive feedback on the ETKs and their use.

We now have a set of proved products and a reasonable process for generating additional ETKs. We have established that teams of undergraduate engineering students can develop effective instructional materials for middle school students.

We have also shown that engineering design challenges and hands-on, project-based cooperative learning, do enhance students' understanding of science and maths concepts.

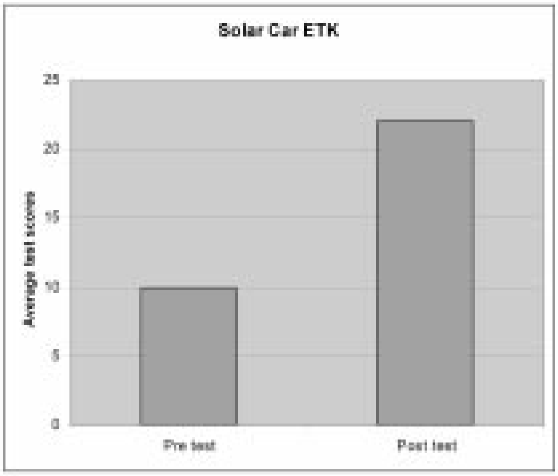

Fig. 6. Average pre- and posttest scores for the Solar Car ETK

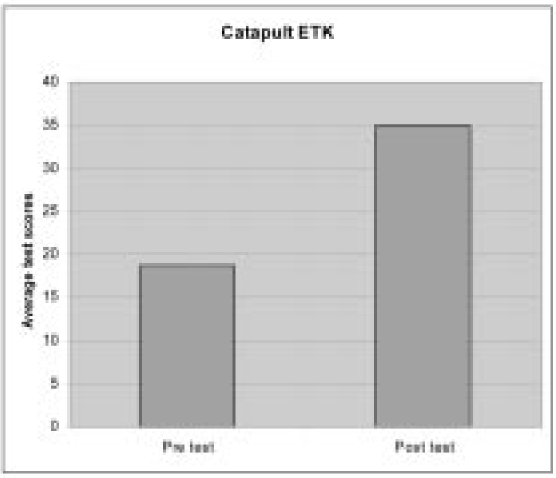

Fig. 7. Average pre- and posttest scores for the Catapult ETK

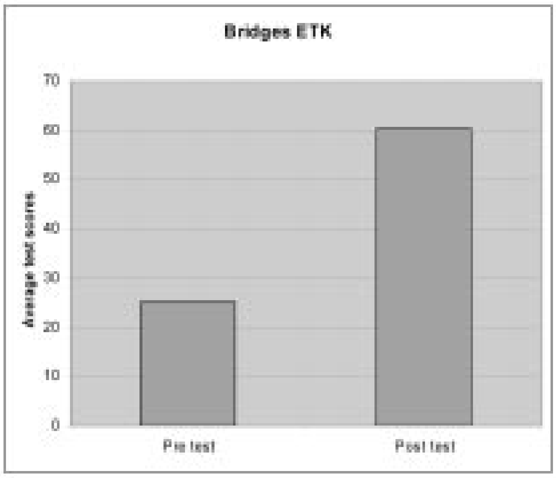

Fig. 8. Average pre- and posttest scores for the Bridges ETK

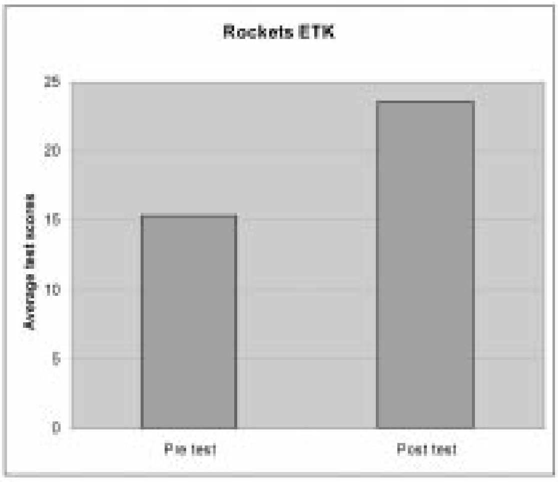

Fig. 9. Average pre- and posttest scores for the Rockets ETK

The motivational effects of bringing ETKs into a classroom have been obvious from the start. The ETKs capture the students' attention and excite them. They become totally involved in the experiments and design challenge.

Interpersonal factors also provide motivation; having someone new and different visit the class is itself interesting and stimulating. And there is the role model effect—seeing that women are mechanical and aerospace engineers opens new vistas for young girls. African American and Hispanic students may also serve as role models. Because our university students teach the ETK their team developed, they represent the school and the engineering profession to the middle school classes.

The data in this paper establish some of the cognitive effects of ETKs. We now have evidence that supports the effectiveness of several ETKs in promoting the learning of science and engineering concepts. To determine whether we have made a difference in the career aspirations and long-term achievement of these students will require a different kind of study.

What else needs to be done? We now need to address national (and international) distribution of our ETKs. How can we package, distribute and support these materials? The interest and demand is beyond our current organizational structure, but we want to be more than just a demonstration site. Our goal is to have a significant impact on the future of middle school science and math education. We hope to make a difference in how students learn science and maths and to motivate them to pursue studies that could lead to careers in engineering.

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