

AC 2008-513: TEACHER AND STUDENT FEEDBACK ABOUT ENGINEERING DESIGN IN MIDDLE SCHOOL SCIENCE CLASSROOMS: A PILOT STUDY

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Teacher and Student Feedback about Engineering Design in Middle School Science Classrooms: A Pilot Study

Abstract

In this study, middle school teachers and students provide critical feedback about three design-based science teaching kits so that the curricula can be refined and improved such that student learning and engagement in science and engineering is maximized. The curricula, packaged as kits, focus on a well-defined set of concepts in science. All lesson plans include a final design challenge. The middle school students must use the scientific and mathematical knowledge and methods they have learned to design, build, and test a working artifact to achieve a goal. Teachers felt that improvements could be made with each kit to enhance student engagement and learning, and some teachers enacted changes during their course of teaching with the kit. Teachers perceived that all three kits increased students' engagement and learning in science. Students enjoyed each of the three kits, thought learning with them was fun, and understood the teachers' learning objectives. Students thought that the best part of the entire unit was the design and construction of the engineered device. The curricula have the ability to help teachers not only teach required science content, but allow students to master standards-based science content in a science reforms-based manner, through inquiry, active, and situated learning.

Introduction: Design-based science

Reform efforts in science education emphasize a shift from teacher-centered to student-centered classrooms^{1,2}. Students construct an understanding of the natural world in much the same way that scientists do, through active engagement in the process of inquiry. Effective teachers expose their students to a variety of teaching strategies, engaging their students in different ways. The active process of learning involves both mental and physical activities as students work with their teachers and peers². When engaged in active learning, students make gains not only in content knowledge, but in process skills and attitudes towards science. When teachers use a curriculum based on active learning, their behaviors also become more student centered, with less focus on worksheets and lectures, and more focus on lab work and inquiry³. In general, active learning reaches students who possess a wide variety of learning styles, much more so than traditional teaching and learning⁴.

In contrast to traditional lecture-style classrooms, active learning takes place when teachers engage students such that they think about and perform meaningful activities. This can be as simple as pausing several times during a lecture and asking students to clarify their notes with another student. However, thoughtfully designed activities can promote student engagement to a much higher degree, and student engagement is highly correlated with academic success⁵.

One type of active learning, problem-based learning, is based on content-specific problems. Problem-based learning (PBL)⁶ is a teaching and learning method where problems relevant to the curriculum provide the context and motivation for all the activities that follow. PBL started in the mid 1950s in North American health sciences education and emerged as an ethical and practical way to give beginning medical students practice solving problems in simulated cases

before working with living patients. Problem-based learning has been used in over 60 medical schools in addition to schools of business, education, architecture, law, and engineering⁷. Problem-based learning has also been used in K-12 schools. In problem-based learning, the learners are immersed in a particular, practical context, often a student-chosen context. One goal of problem-based learning is to help students develop an intrinsic motivation to learn. Since students are more motivated to learn when they see value in what they are learning, it is important that students or teachers choose problems that are relevant for the students⁸.

Theoretical Framework

Problem-based learning and other active learning strategies are based on the theoretical framework of social constructivism. Essentially, social constructivists believe that knowledge is created in the context of the situation in which it was developed. Learners construct meaning through active engagement, not passive listening. Learners use and apply their knowledge to carry out investigations and create artifacts that represent their understanding. Learners work within a social context as they use language to express and debate their ideas. Learners engage in authentic tasks that are relevant to the student and connected with their lives outside of the school setting, and the role of the teacher is to help learners construct their knowledge through scaffolding and coaching⁹.

The instructional principles of constructivism imply that learning activities are anchored within a larger purpose, that the learner takes ownership for his or her goals in learning, and that the tasks are authentic. The learner does not merely memorize and regurgitate facts, but engages in authentic activities related to the instructional goals. Learners use all sorts of resources and sources of information to support their inquiry. Students take ownership for learning and problem solving, while a teacher encourages and challenges the pupils. Teachers take on the role of consultant or coach, challenging the learners as well as valuing their process of learning. The teacher does not tell the students how to think or what to do⁷.

One active teaching and learning methodology that falls under the framework of constructivism is design-based science. Closely related to problem-based science, design activities can be thought of as a type of problem solving. Just as situated learning theory^{10, 11} looks at how students learn best situated in the context of authentic activities, design-based science has students learning science through solving authentic problems.

Design is to engineering what inquiry is to science¹². They are both problem-solving activities that use cognitive reasoning, mental models, evaluation, rely on content knowledge, and operate within constraints¹³.

Design-based science activities center on student-designed, built, and tested artifacts. If carefully planned to match design activities with science concepts, students can learn and apply scientific principles as they strive to design, build, modify, and test a device (an artifact). Design became a topic of discussion in science education in 1993 when the American Association for the Advancement of Science (AAAS) published *Benchmarks for Scientific Literacy*¹. The AAAS stated that while design projects are common in the elementary grades, that all students should

become familiar with design and technology projects in order to engage in problem-solving in real-world contexts.

The National Research Council (NRC)² followed suit in 1996 with its own recommendations on how science should be taught. The NRC's *National Science Education Standards* included an emphasis on students' abilities to design solutions to problems in much the same way that inquiry is conducted to answer scientific research questions. The NRC stated that young children should be conducting design activities. "Children can engage in projects that are appropriately challenging for their developmental level - ones in which they must design a way to fasten, move, or communicate (p. 135)." This recommendation comes closer to design-based science because the NRC recommended that design tasks should be related to science content standards.

Additionally, although an emphasis on technological literacy is present in three major educational reform documents, the *Benchmarks for Science Literacy*¹, the *National Science Education Standards*², and the International Technology Education Association's *Standards for Technological Literacy*¹², there is virtually no emphasis placed on technological literacy in today's K-12 curricula in the United States. This is in stark contrast to other industrialized countries (e.g. France, Italy, Japan, the Netherlands, Taiwan, and the United Kingdom) that put emphasis on technology education^{14, 12, 15}.

The National Academy of Engineering has a thorough description of a technologically literate person in its book, *Technically Speaking: Why All Americans Need to Know More about Technology*, written by the Academy's Committee on Technological Literacy¹⁵. It states that a technologically literate person is one who recognizes technology, understands the difference between science and technology, knows some basic concepts about technology, understands the goals and trade-offs implicit in the engineering design process, recognizes how technology has influenced society through the ages, and as well recognizes how society has also shaped technological advances, understands that using technology entails risks, and that all technology has both benefits and costs. A technologically literate person understands that technologies are neither inherently good nor evil, and that the values of a culture or society are reflected in the technologies that the culture or society embraces. A technologically literate person should have some hands-on skills with tools and devices so that he or she has the ability to diagnose and fix certain problems such as a flat tire or a tripped circuit breaker, and finally, a technologically literate person should be able to participate in public debates and discussions about technological issues, and cogently communicate his or her ideas about technology. Through design-based science curricula - if they are properly written and developed - students have the potential to meet both science literacy and technological literacy goals.

Students can engage in design-based science at any age, while learning any content area of science. A primary research group investigating design-based science is at the University of Michigan where Design-Based Science (DBS) curriculum units have been created and tested for use with high school and middle school students^{16, 17}. Curriculum units are being created and tested for use with middle school students through the Georgia Institute of Technology's Learning by Design™ (LBD™) program^{18, 19, 20}, and through the University of Pittsburgh's Learning Research and Development Center²¹. The Boston Museum of Science has published the Engineering is Elementary (EiE) curriculum for elementary school students, and it is

undergoing research-based evaluation ²². The University of Virginia has also created design-based science kits for middle school teachers but the curricula has yet to be properly analyzed for its impact on students' science knowledge and understanding ^{23, 24, 25}.

The study context: Developing design-based science curricula

For the past six years, engineering and education students and faculty at the University of Virginia have been working with middle school teachers to bring engineering curricula into their classrooms. Topics from science, math, and technology that have interesting engineering applications have been identified and engineering teaching kits are developed to help middle school students learn science and math in the context of engineering design. The curricula, packaged as kits, focus on a well-defined set of concepts in science or math. All lesson plans include a final design challenge. The middle school students must use the scientific and mathematical knowledge and methods they have learned to design, build, and test a working artifact to achieve a goal.

Each Engineering Teaching Kit (ETK) includes hands-on experimentation, data gathering and summarization, and evidence-based reasoning and design. The middle school students work in teams on a series of tasks and projects. The curricula are carefully constructed to facilitate the students' learning of particular concepts and methods through what is called guided inquiry ²⁶.

Over the past six years 30 of these kits have been used in local middle schools. So far over 2000 middle school students and 30 middle school teachers have used these materials. In this study, three kits have been pilot tested with three middle school teachers and their students. The kits are: Save the Penguins, Hovercrafts, and Solar Cars.

Save the Penguins

The Save the Penguins kit is designed to help students learn about and apply:

- 1) heat transfer concepts of convection, conduction, and radiation,
- 2) process skills of experimental methodology and measurements, and
- 3) the environmental science concept of climate change and its impact on animal populations.

In this kit, students work in collaborative groups of 2-4. They are given a budget of pretend money that they can spend to purchase building supplies. Their design challenge is to build a dwelling that will keep a 10 gram penguin-shaped ice cube from melting (Figure 1).



Figure 1: The penguin-shaped ice cube on blue mesh.

Building supplies consist of common materials such as cotton balls, Popsicle sticks, aluminum foil, coffee cups, and foam packaging peanuts (Figure 2).



Figure 2: Student-designed dwellings for ice penguins.

In warm weather, the design challenge takes place outside on an asphalt surface. In cold weather, the design challenge takes place indoors under heat lamps. The teacher frontloads students with information about heat transfer, environmental science, and necessary process skills. The teacher might perform demonstrations of heat transfer; show a presentation about climate change or perhaps a video about penguins. Experimental methods and measurement techniques are practiced as students test different materials in order to begin forming a tentative dwelling design. In addition to the dwelling, students create posters (Figure 3) which contain drawings of design diagrams, experimental designs and results, materials used and money spent. The goal is

for students to apply the learning and behavioral objectives in the process of designing, constructing, re-designing, and testing their dwelling.

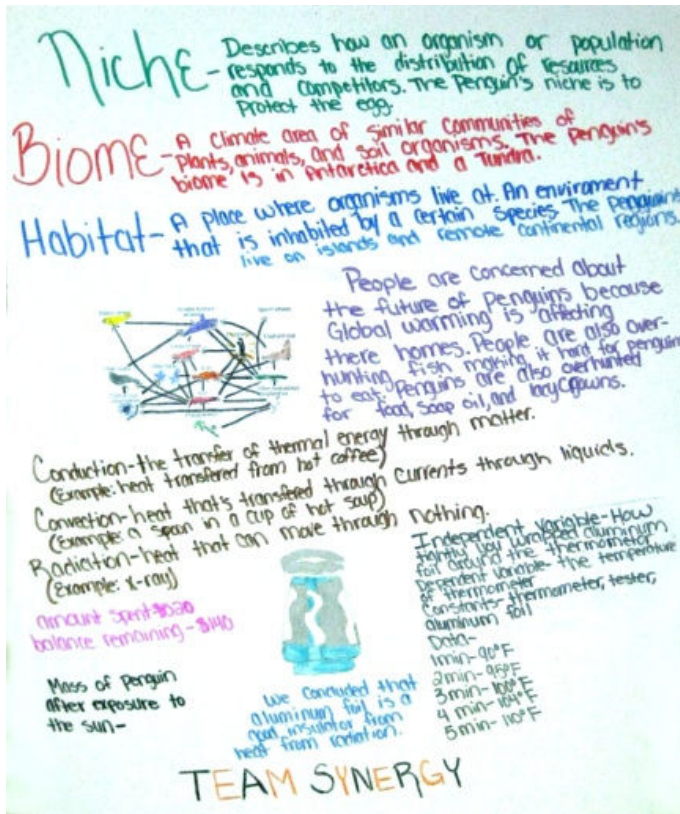


Figure 3. A poster created by one student group.

Hovercrafts

The Hovercrafts kit is designed to help students learn about and apply:

- 1) concepts about electrical circuits involving batteries, motors, and switches,
- 2) process skills of experimental methodology and circuit construction, and
- 3) the physical science concepts of force and motion, friction, drag, lift, and propulsion.

In this kit, students work in collaborative groups of 3-4. Their design challenge is to build a craft (Figure 4) that will both hover and move forwards. Building supplies consist of common materials such as Styrofoam cups and plates, motors with fans, wire, switches, grocery bags, and tape.



Figure 4. A student-designed hovercraft with warning sign.

The design competition can take place indoors on a flat surface such as a hallway or gymnasium. The teacher can either frontload students with information about circuit design, forces and motion, or the students can learn these concepts on a need-to-know basis. In the process of building a working hovercraft, many practical science concepts need to be mastered for building success. The teacher might perform demonstrations about Newton's Laws, teach students about the difference between parallel and series circuits, and demonstrate how to strip wire and properly connect devices. Experimental methods and construction techniques are practiced as students test different design configurations in order to create a successful craft. In addition to building a working hovercraft, students keep design diaries in which they record questions asked and answered, sketches and designs attempted, failures and successes, and the final design drawing. The goal is for students to apply the learning and behavioral objectives in the process of designing, constructing, re-designing, and testing their hovercraft.

Solar Cars

The Solar Cars kit is designed to help students learn about and apply:

- 1) concepts about electrical circuits involving solar cells, motors, and gears,
- 2) concepts about how energy can change forms (i.e. solar to electrical to mechanical)
- 3) process skills of experimental methodology and circuit construction, and
- 4) the physical science concepts of force, friction, and conservation of energy.

In this kit, students work in collaborative groups of 3-4. Their design challenge is to build a solar-powered vehicle that will pull a cart carrying the most weight (Figure 5). Building supplies consist of Lego-brand blocks and gears, high-torque motors, solar panels, rubber bands, duct tape, and wire nuts.



Figure 5. A student-designed solar car.

The design competition should take place outdoors in the sun, on a flat surface such as a sidewalk or running track. The teacher frontloads students with information about circuits, how solar cells work, how motors work, and how energy can be converted from one form to another with losses usually taking place. Students then test three different motors, three different solar panels, and different wheel-covering materials to select the best options for their car. The Lego parts are considered “free”, but students must purchase a motor, solar cell, and wheel coverings from a budget. In the process of building a solar car, many practical science concepts need to be mastered for building success. Students need to learn how to use a force meter, how to use a volt meter, and how to wire series and parallel circuits. Experimental methods and construction techniques are practiced as students test different design configurations in order to create a successful car. Students test their cars by seeing how much weight it can pull in a cart attached to the rear of their vehicle (Figure 6).



Figure 6. Student tests the solar car with a cart full of weights.

The goal is for students to apply the learning and behavioral objectives in the process of designing, constructing, re-designing, and testing their solar car.

Goals of current study

In this study, middle school teachers and students provide critical feedback about three of the ETKs so that the curricula can be refined and improved such that student learning and engagement in science and engineering is maximized, and so that state and national science standards can be met. Engineering design activities will not be readily accepted by science teachers if they do not facilitate the teaching and learning of required science objectives.

This early research will provide the basis for a more extensive study which will inform the science education and engineering education communities about how engineering design problems can be used to engage students in science concepts, and expose them to the engineering design process. The deeper issue is whether students benefit from this instructional methodology. Feedback from teachers and students will generate ideas and refinements that will lead to a future, more formal evaluation of design-based science in this context. The formal evaluation will be designed to determine whether learning science through engineering design can help students comprehend scientific ideas at a deeper conceptual level, and whether it increases student interest in science and engineering.

Methods

Participants and Sites

Three female science teachers and 99 middle school students at Countryside Middle School²⁷, a rural public middle school in a Mid-Atlantic state, participated in the study. Countryside has a student population of 415 with 20% being minority students and 31% eligible for free or reduced lunch²⁸. Countryside Middle School serves families with the lowest socioeconomic status compared with the other three public middle schools in the county. Teacher participants ranged in age from 44 to 55 with 6 to 30 years of science teaching experience. Student participants ranged in age from 11 to 14 years old. The sampling criteria included voluntary participation from the teachers, voluntary participation from the students and consent from their parents/guardians, as well as permission from the principal of the school and the county director of research. Cathy taught 6th grade science and tested all three kits with one regular-level class of 24. Stacey taught both 6th and 7th grade science and only tested the Save the Penguins kit with one lower-level 6th grade class of 17. Janice taught 8th grade science and used the Save the Penguins kit with all three of her classes (low, regular-level, and honors-level) totaling 58 students.

Data Collection

Two major data sources were used to characterize the participants' views about the three different design-based science kits; semi-structured teacher interviews after the kits were used, and evaluation surveys completed by students.

Interviews with the three teachers were conducted at the conclusion of the semester (January, 2008). They lasted approximately 30 minutes each. The interview protocol was developed and pilot tested for a previous study which examined teachers' impressions of newly-developed and

field-tested kits²⁵. One goal of this study is to develop a valid and reliable interview protocol to administer to all teachers who participate in field trials of ETKs as they are developed and tested.

The set of seven questions provided a framework for the interview (Appendix A), but the interviewer made extensive use of follow-up questions to elicit more thoughts and ideas as they were revealed during the interviews. Additionally, each teacher showed the interviewer examples of student work and told stories about students and teams of students who had participated in the engineering design activities. All the interviews were audiotaped and transcribed for later analysis.

Three student evaluation surveys were used in this study, one for each kit (Appendixes B, C, and D). The evaluation survey was originally designed by a student team of mechanical engineering students at the University of Virginia in 2006 for a kit they developed on making headphone speakers. The survey was modified for the kits in this study.

Each survey consisted of 10 Likert-scale questions and three open-ended questions. The Likert-scale questions were about teamwork, the design process, content, perceived learning, fun, challenge, and success. The open-ended questions elicited responses about what students learned, what they liked about the kit and what they disliked. Each survey was identical except that two of the content-based Likert-scale questions changed to reflect the content of each kit. Student evaluation surveys were distributed on the last day that the teacher used the kit. Judith administered the surveys to her students over the course of two days as her three classes finished the Save the Penguins kit. Stacey administered the survey to her one class who used the Save the Penguins kit the day after their design competition. Cathy administered each of the three surveys the day after each design competition. The immediacy of students' completing the survey took advantage of their memories and reactions to the science lessons, design activities and the design challenge. The surveys were completed anonymously. The researcher assigned each survey a code number and entered the data into an Excel spreadsheet for analysis.

These two types of data allowed the researcher to characterize the curricula from the viewpoint of both teacher and student. In this study, the responses from teachers and students were aligned closely enough that they could be reported with confidence as preliminary data.

Data Analysis

Data analysis followed an analytic induction process as described by Erickson²⁹. The researcher reviewed the data sources with the goal of characterizing how the kits were perceived by different groups of students, and by different teachers.

The first analytic task involved looking at the student surveys and computing means for questions, classes, and kits, and comparing these for an overall picture of student feedback. Next, student responses to the open ended questions were given preliminary codes (i.e. team work troubles, making the device, getting hurt, the final challenge, losing). These codes were collapsed and condensed as trends and patterns were recognized. Trends and patterns in the open-ended questions were compared to the Likert-scale question trends to look for correlations.

The third analytic task involved coding the teacher interviews, again looking for patterns and trends. The patterns and trends across both student and teacher groups were used to develop preliminary assertions, which the researcher further refined by comparing them to the original data sources. Several iterations of this process resulted in a manageable set of six assertions, well supported by the data. Finally, the researcher looked for disconfirming evidence, and used this information to further refine the assertions.

Results

The purpose of this study is to explore teachers' and students' opinions about three particular kits; Save the Penguins, Hovercrafts, and Solar Cars. Specifically, the study addresses the following questions:

1. What do teachers perceive to be the effects on student engagement and science learning when different kits are used in their classrooms?
2. How do students experience the different kits?
3. Compared with the learning objectives held by the teacher, what learning objectives do students think have been met through the kits?

To answer these questions, the researcher posed the following six assertions after careful data analysis.

Assertion 1: Teachers perceived that all three kits increased students' engagement and learning in science.

All three teachers remarked that using the kits increased student engagement and learning during the course of the intervention. Cathy stated that students were "very excited and anxious to start each day" during the engineering design units, and that they would beg her to work on their designs during study hall and lunch.

They were so proud that they could go home and tell their parents that they built a solar car or they had built a hovercraft. They were doing things they had never done before, and things that they didn't think they were capable of doing. (Cathy, Exit Interview)

Students in Cathy's class were successfully building electrical circuits for the first time in their lives. They also learned how to use a multi-meter and could test both the voltage of batteries and of the solar panels when light was shining on them. They especially learned about radiation from the Save the Penguins kit, more so than other forms of heat transfer. The Hovercraft kit was instrumental for students to learn about forces and motion.

They learned that in order for air to exert a force, it has to flow and if the air flow was occluded, they didn't get the force. They also learned that in order for the hovercraft to move forwards, it had to push air backwards, not at an angle... (Cathy, Exit Interview)

Stacey remarked that her (low level) students were more willing to "stick their necks out" with the Save the Penguins kit, and that doing the design activities wasn't as threatening to them as reading or writing. "They were actively participating, not reading or writing which is one of their weaknesses."

Judith remarked that her students were all very engaged in the design and testing process during the Save the Penguins kit, but less engaged in the process of creating a poster afterwards. She said that engagement was the greatest benefit of using the kit with her students.

It was fun. It was just fun. That's important to me that they see science as being fun and I think that's one of them most important things to me and they did retain what they learned and they took it outside of the classroom and talked to their parents. (Judith, Exit Interview)

Judith also commented that her students learned a lot, even things that she took for granted that they would already know. She said,

I thought they would all know that black paper would absorb the heat and white paper would not. They didn't. I saw them buying black paper so I think they did learn a lot and I think they learned a lot about conduction and insulating the igloos. (Judith, Exit Interview)

Students also learned from each others' mistakes. One group did not account for the radiant heat coming up from the surface below the penguin dwelling. They thought that their igloo would block the heat, but they quickly realized their mistake when their penguin ice cube began to rapidly melt. The winning dwelling, she said, had a well insulated base for the ice penguin to rest on. For a post-test, she had students conduct a card sort where they had to match up examples of heat transfer with the form of heat transfer described, and she said they did well with that task.

Assertion 2: Teachers noted changes they would make in the curriculum if they were to teach it again.

The first teacher to use the Save the Penguins kit was Cathy. She passed on her suggestions for change to Stacey, who used the kit second. Judith used the kit last, incorporated some of the suggestions from her colleagues, and still came up with more to implement in the future.

Cathy noted that the kit did a good job of teaching radiation and convection, but that it needed something more to help students learn conduction since the ice cube had been resting on a plastic mesh taped to the top of a plastic cup. She had students create posters on stick-backed whiteboards they would adhere to the walls of the classroom. She suggested that future classes use poster board with colored markers since the black dry-erase ink would easily brush off the whiteboards. She also became frustrated cutting materials to sell to students, and suggested that materials be pre-cut for ease of quickly selling.

Stacey implemented several of these suggestions. She used poster board and colored markers, pre-cut the materials for easy distribution, but did not think of a way to solve the problem of the ice cube lacking much heat conduction in its melting process. She said that one downside to the way the lessons were designed was that students did not have to directly link which building material affected which type of potential heat transfer

Judith implemented all the suggested modifications during her use of the heat transfer kit. She used poster board and colored markers, pre-cut the materials for easy distribution, and pre-heated the black countertop in her classroom with a heat lamp, and had students rest their ice cube penguin on a small piece of paper directly on the heated surface. This provided both radiant heat from above in the form of a heat lamp, radiant heat from the black counter below, and conduction as the ice cube was almost in direct contact with the heated counter. Judith also expressed concern that students did not always link their choice of building material with blocking a particular type of heat transfer, and suggested that students graphically illustrate this on their posters in the future. Also, Judith had students find the mass of their ice cube just before putting it under the igloo, and then find the mass at the end of the trial to find the mass lost. Both Cathy and Stacey had created the ice cubes with 10 ml of water, so they assumed that the pre-testing mass would be 10 grams, but Judith found out that non-uniform sublimation in the freezer could vary the masses of different ice cubes and introduce error into the final results.

Cathy was the only teacher to use the Hovercraft and Solar Car kits. During the Hovercraft unit, she experienced frustration with the rapidly spinning Hovercraft propellers, and suggested that the kit be used with older students who might be more careful with their fingers. She had nearly half of her students receive cuts to their fingers while building and testing the vehicles and this gave her tremendous anxiety. One student even had a cut penetrate his fingernail while using a pair of scissors to trim Styrofoam.

The propellers were loud and scary-sounding and if the propeller was not perfectly attached to the hovercraft, it might rub up against some Styrofoam and make a lot of noise. So the classroom was very noisy and every time I heard it get noisy I was afraid someone would get hurt. So this produced a lot of anxiety for me. (Cathy, Exit Interview)

During the Solar Car unit, Cathy experienced frustration with the multitude of Lego parts available to students in sorted plastic bins at the front of the room, and suggested that each student team be given a baggie full of parts to use, so that clean up would not require time-consuming re-sorting of small parts. She also had students wanting to go outside to test their cars, and found the need to be in two places at once. She remarked that she should have brought some lamps into the classroom with long cords. They were available, but she thought they would be too hot and might injure students. She suggested that using lower-wattage incandescent “shop lights” instead of halogen “shop lights” would be a good compromise.

Assertion 3: Students enjoyed each of the three kits and thought learning with them was fun.

All students were asked to rate whether they thought the learning experience was fun on a scale of 1 to 10, with 10 being the most fun, and these results corroborated the teachers’ perceptions (see Table 1). The Fun Factor was calculated as the mean of students’ self-reported rating.

Table 1. Students' perception of how "fun" the design-based science kit was.

Teacher	Kit	Academic Level	Fun Factor
Cathy	Save the Penguins	Regular-Ed	8.48
Cathy	Hovercraft	Regular-Ed	8.46
Cathy	Solar Car	Regular-Ed	8.64
Judith	Save the Penguins	Low Level	8.33
Judith	Save the Penguins	Regular-Ed	7.74
Judith	Save the Penguins	Honors Level	8.25
Stacey	Save the Penguins	Low	8.94

The evaluation survey administered to students contained questions related to learning, fun, challenge, success, team work, engineering design, and specific science content. They were asked to rate how much they learned on a scale from 1 to 10, with 10 representing the most learning (see Table 2). The Learning Factor was calculated as the mean of the students' self reported degree of learning.

Table 2. Students' perception of how much they learned from each kit.

Teacher	Kit	Academic Level	Learning Factor
Cathy	Save the Penguins	Regular-Ed	8.05
Cathy	Hovercraft	Regular-Ed	7.21
Cathy	Solar Car	Regular-Ed	8.14
Judith	Save the Penguins	Low Level	8.00
Judith	Save the Penguins	Regular-Ed	6.36
Judith	Save the Penguins	Honors Level	7.45
Stacey	Save the Penguins	Low Level	8.65

Interestingly enough, the greatest amount of self-reported learning was in Stacey's low-level science class after they used the Save the Penguins curriculum. The "Fun Factor" from this class was the highest from the group as well. The same correlation applies to Judith's Regular-Ed

class. They rated the kit as the least fun and rated their learning as the least. It seems that learning and fun do go together, at least from the students' perspective.

Assertion 4: Students understood the teachers' learning objectives and were able to articulate them.

Students were asked on the evaluation survey, "What was your teacher trying to teach you?" and as a whole, 71% of students were able to articulate at least one of the learning objectives of the unit. Table 3 shows a breakdown of how often students were able to articulate the teaching objectives of each kit.

Table 3. Students' perception of learning objectives correlated to teachers' objectives.

Teacher	Kit	Academic Level	Number of positive responses	Class Size	Percentage of positive responses
Cathy	Save the Penguins	Regular-Ed	15	21	71%
Cathy	Hovercraft	Regular-Ed	16	24	67%
Cathy	Solar Car	Regular-Ed	18	22	82%
Judith	Save the Penguins	Low Level	10	15	67%
Judith	Save the Penguins	Regular-Ed	16	23	70%
Judith	Save the Penguins	Honors Level	18	20	90%
Stacey	Save the Penguins	Low Level	8	17	47%

Overall, 67% of students from the class involved in the Hovercraft kit were able to articulate the correct learning objectives. Samples of student responses that typified the positive responses are detailed below.

"How circuits work and how to create electrical circuits." (Student 2SH)

"How to connect circuits and the push and pull force of how things can be lifted." (Student 11SH)

"How to create kinds of circuits and connect them to make a motor work without it exploding or getting really really hot." (Student 13SH)

"To learn forces and different circuits." (Student 19SH)

70% of students from five classes involved in the Save the Penguins kit were able to articulate the correct learning objectives. Samples of student responses that typified the positive responses are detailed below.

"She was trying to teach us about convection, conduction, and radiation." (Student 6HSP)

"What things you can do to make your house warm and cold." (Student 13LSP)

“What was good for conducting and insulating heat.” (Student 16LSP)
 “She was trying to teach about heat transfer.” (Student 31LSP)
 “What kinds of materials can insulate or reflect heat.” (Student 41LSP)
 “About some engineering and heat capacity and also the transfer of heat.” (Student 17SSP)

82% of students involved in the Solar Car kit were able to articulate the correct learning objectives. Samples of student responses that typified the positive responses are detailed below.

“How other energies such as solar energy can be used to turn into other energies such as kinetic energy.” (Student 5SSC)
 “She was trying to teach us how energy can change.” (Student 12SSC)
 “How to make a solar car from the sun’s rays to move.” (Student 14SSC)
 “Comprehension of electricity and solar power.” (Student 18SSC)

The students who did not answer this question with an articulation of at least one of the teacher’s learning objectives either left the answer blank, wrote something like, “science” or “yes” or “stuff” or “I really don’t know” or ill-defined statements such as, “to save the penguins” or “how to keep our penguin alive.”

Assertion 5: Students thought that the best part of the entire unit was the design and construction of the engineered device.

Students were asked what the best part of the experience was, and the most frequent answer referred to the design and construction of the solar car, hovercraft, or penguin dwelling. Ninety-nine students answered this question about their experiences. Their answers fell into five general categories:

- 1) making the house/car/hovercraft
- 2) the final design competition
- 3) working on a team
- 4) it was fun
- 5) making the poster

Some students did not answer this question, and others put down more than one answer so the percentages in Table 4 do not always add up to 100% for each class.

Table 4. Students’ report of the “best part” of the entire unit of study.

Teacher	Academic Level	Activity	Making the device	Design competition	Team work	Having fun	Making the poster
Cathy	Regular-Ed	House	43%	19%	14%	14%	0%
Judith	Low Level	House	40%	27%	7%	0%	n/a
Judith	Regular-Ed	House	52%	13%	26%	0%	13%

Judith	Honors Level	House	50%	30%	20%	0%	15%
Stacey	Low Level	House	47%	24%	18%	6%	0%
Cathy	Regular-Ed	Car	41%	18%	9%	14%	n/a
Cathy	Regular-Ed	Hovercraft	42%	n/a	17%	13%	n/a

Making the device and participating in the design competition were clearly the students' favorite parts of the unit of study. There was no design competition for the hovercraft kit that Cathy taught because none of her students could successfully finish the project in two weeks' time, which was as much time as she could reasonably devote to the activity. Also, only four groups doing the Save the Penguins kit were required to make posters about their designs, experiments, expenses, and ideas.

Assertion 6: Students thought that the worst part of the entire unit was losing the design competition.

Students were asked what the worst part of the experience was, and the most frequent answer overall was losing; 20% of all answers referred to some aspect of losing as the worst part of the experience. The next most frequent answer overall was about the teams students worked with; 16% of students referred to working with their teammates as the worst part of the experience. Other aspects of the projects students did not like were making a poster, getting hurt, and not being able to get the car or hovercraft to work (Table 5). Approximately 13% of students overall responded with the phrase, "Nothing was the worst part".

Table 5. Students' report overall of the "worst part" of the entire unit of study.

Losing	Team work	Making the poster	"Nothing"	Getting the car or hovercraft to work	Getting hurt
20%	16%	15%	13%	8%	5%

The most frequent answers about the Hovercraft kit referred to getting hurt and frustration getting the vehicle to work. The most frequent answers about the Solar Car kit referred to difficulty with the team. The most frequent answers about the Save the Penguins kit referred to losing, making the poster, and the working with the team (Table 6).

Table 6. Students' reports for each kit about the "worst part" of the unit of study.

	Losing	Team work	Making the poster	"Nothing"	Getting the car or hovercraft to work	Getting hurt
Hovercraft	n/a	8%	n/a	17%	25%	25%
Solar Car	9%	32%	n/a	14%	18%	0%
Save the Penguins	26%	13%	21%	11%	8%	0%

Losing was not an issue for students in Cathy's class doing the Hovercraft project since none of the students completed the design successfully. The class was too busy getting hurt and trying to get the hovercraft to actually move and hover.

Teams were assigned when Cathy taught with the Hovercraft kit and the Solar Car kit. Solar Car teams were based on gender- only groups of girls and groups of boys were assigned. Team work proved to be the biggest disappointment for students in Cathy's class while building solar cars. This unit was begun in the second month of the school year just as Cathy was getting to know the students well, but she assigned students to gender segregated lab groups before they ever entered the classroom in August. Perhaps if she had assigned teams after this first month, taking their personalities and friendships into consideration, the team dynamics would have been ameliorated. When students were allowed to pick their own teams, they did not have as many teamwork issues. Cathy, Judith, and Stacey did not assign groups for the Save the Penguins kit, and only 13% of students overall claimed that teamwork was the worst part of that experience. Cathy did not assign teams for the hovercraft project, and only 8% stated that teamwork was the worst part of that experience.

Discussion

The purpose of this study was to explore teachers' and students' opinions about three particular engineering teaching kits; Save the Penguins, Hovercrafts, and Solar Cars. A thorough analysis of the data sources allowed for the researcher to answer these questions with a high degree of confidence.

Question 1: What do teachers perceive to be the effects on student engagement and science learning when different kits are used in their classrooms?

All three teachers in this study gained a perspective that their students were engaged with the topics and activities presented to them, and that they learned significant science through the process of using the different kits. Students were actively participating, talking about the projects outside of class and at home, and they responded well to unit assessments afterwards. Teachers felt that improvements could be made with each kit to enhance student engagement and learning, and some teachers enacted changes during their course of teaching with the kit. All teachers incorporated the use of posters for evaluative assessment of student team learning in the Save the

Penguins kit. While Cathy and Stacey did not discuss many classroom issues with the use of student team-created posters, Judith expressed frustration that her students were not engaged in making the posters, and were actually putting information onto the poster at the end of the project instead of along the way, as it was designed to be used. While Cathy's students were very engaged in the process of making hovercrafts, and they continued to learn science concepts throughout the two weeks they devoted to building them, their abilities to construct working devices were limited and exceeded the time limit set ahead of time for the use of the kit. This caused both teacher and students frustration. Additionally, roughly half of the students were injured by the propellers or scissors, although none of these were serious.

Question 2: How do students experience the different kits?

Most of the students rated the three kits as fun. On a scale of 1 to 10 with 10 being the most fun, all classes but one rated these three kits with a "Fun Factor" score of 8 or better.

Students also perceived that they learned quite a bit through the use of the kits. Four out of seven classes rated their learning as an 8 or better on a scale of 1 to 10 with 10 representing the most learning.

The favorite part of the entire unit for the students was the design and construction of the engineered device, with the testing of the device coming in second place for "favorite part". Roughly 20% of students stated that working on a team was their favorite part of the process, and very few stated that making the poster was their favorite part. Actually, 15% of students stated that making the poster was the worst part of the whole activity. Losing was another part of the entire package that students did not enjoy; it was the most frequently stated "worst part" of the unit of study. Half of students cited getting hurt and not getting the hovercraft to work as the worst parts of the Hovercraft kit. The frustration students experienced lead the researcher to a re-assessment of how the activity should best be used with middle school students. With 26% of students stating that losing was the worst part of the Save the Penguins kit, this begs the question of how the kit can be redesigned such that there is more than one way to "win". Perhaps each student can build a penguin dwelling, and there can be levels of competition: within group, between groups, and between classes. To reduce the concept of loss and maximize the concept of winning, perhaps the curriculum could be re-designed take advantage of students' intrinsic motivation to improve their designs relative to their own starting point³⁰ rather than to an extrinsic motivation to compete against other student groups.

Question 3: Compared with the learning objectives held by the teacher, what learning objectives do students think have been met through the kits?

This question was answered through students' responses on the open ended question, "What was your teacher trying to teach you?" Over 70% of students in the study were able to correctly articulate at least one of the teachers' learning objectives. While this study did not include a formal assessment of student learning, indications are that they did learn at least some of the teachers' objectives.

In Closing

Research on design-based learning in science is a relatively new field in science education. With universities and other institutions developing design-based learning curricula that expose students to the field of engineering in conjunction with standards-based science content, research needs to take place to assess whether students are making gains in both technological and scientific literacy. In this pilot study of three design-based curricula developed at the University of Virginia, it has been shown that the curricula have the ability to help teachers not only teach required science content, but allow students to master standards-based science content in a science reforms-based manner, through inquiry, active, and situated learning.

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Appendix A
ETK Exit Interview Protocol

Introduction: Our research is focused on how Engineering Teaching Kits can assist teachers in implementing effective science instruction. As a teacher who has used an ETK either alone or with engineering students from UVa, we are interested in your opinion about the kits. In this interview/survey, I'll be asking you questions about how you think the ETK or ETKs you have used have impacted both your teaching and your students. Your responses will be kept confidential. Your name will not be used in any final report. If there is a question you do not wish to answer, you may leave it blank or simply not answer it. Participation in this study is voluntary.

1. Which ETKs have been used in your classroom? Did the UVa engineering students teach the kit, or did you teach it yourself?
2. What do you think the effects were on student engagement while students participated in an ETK? (If you have used multiple ETKs, please provide an answer for each one.)
3. What do you think the effects were on student learning while students participated in an ETK? (If you have used multiple ETKs, please provide an answer for each one.)
4. Was there a particular group of students that the ETK or ETKs attracted or interested more?
5. How comfortable would you feel teaching by yourself with an ETK?
6. What do you see as the greatest benefit of the ETK or ETKs used in your classroom?
7. What frustrations, if any, did you experience as a result of the ETK?

Appendix B
Evaluation Survey for Save the Penguins Kit

DO NOT PUT YOUR NAME ON THIS HANDOUT
Completion of this survey is voluntary. You do not have to complete the survey if you do not want to. You do not have to answer all the questions if you do not want to.

Evaluation Survey

1.) How much did you learn from using the “Save the Penguins” kit (really)?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

2.) How much fun was this experience (really)?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

3.) How challenging was this experience?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

4.) How successful was your final product?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

5.) How much did you enjoy working in a team?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

6.) How much did everyone on your team contribute?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

7.) How well do you understand the concept of heat and how solar energy can be transformed into heat?

1 2 3 4 5 6 7 8 9 10

Not at

No Opinion

Very

8.) How well do you understand convection, conduction and radiation?

1 2 3 4 5 6 7 8 9 10

Not at

No Opinion

Very

9.) How well do you understand the design process?

1 2 3 4 5 6 7 8 9 10

Not at

No Opinion

Very

10.) Was your teacher effective at helping you learn science through engineering design?

1 2 3 4 5 6 7 8 9 10

Not at

No Opinion

Very

11.) What was your teacher trying to teach you?

12.) What was the best part about this experience?

13.) What was the worst part about this experience?

Appendix C
Evaluation Survey for Solar Car Kit

DO NOT PUT YOUR NAME ON THIS HANDOUT
Completion of this survey is voluntary. You do not have to complete the survey if you do not want to. You do not have to answer all the questions if you do not want to.

Evaluation Survey

1.) How much did you learn from using the solar car kit (really)?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

2.) How much fun was this experience (really)?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

3.) How challenging was this experience?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

4.) How successful was your final product?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

5.) How much did you enjoy working in a team?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

6.) How much did everyone on your team contribute?

1 2 3 4 5 6 7 8 9 10

Not at No Opinion Very

7.) How well do you understand the concept of energy and how energy can be transformed from one type to another (example: solar to electrical)?

1 2 3 4 5 6 7 8 9 10
Not at No Opinion Very

8.) How well do you understand how motors use electrical energy to make kinetic energy?

1 2 3 4 5 6 7 8 9 10
Not at No Opinion Very

9.) How well do you understand the design process?

1 2 3 4 5 6 7 8 9 10
Not at No Opinion Very

10.) Was your teacher effective at helping you learn science through engineering design?

1 2 3 4 5 6 7 8 9 10
Not at No Opinion Very

11.) What was your teacher trying to teach you?

12.) What was the best part about this experience?

13.) What was the worst part about this experience?

Appendix D
Evaluation Survey for Hovercraft Kit

DO NOT PUT YOUR NAME ON THIS HANDOUT
Completion of this survey is voluntary. You do not have to complete the survey if you do not want to. You do not have to answer all the questions if you do not want to.

Evaluation Survey

1.) How much did you learn from using the hovercraft kit (really)?

1 2 3 4 5 6 7 8 9 10

Not at

Very

2.) How much fun was this experience (really)?

1 2 3 4 5 6 7 8 9 10

Not at

Very

3.) How challenging was this experience?

1 2 3 4 5 6 7 8 9 10

Not at

Very

4.) How successful was your final product?

1 2 3 4 5 6 7 8 9 10

Not at

Very

5.) How much did you enjoy working in a team?

1 2 3 4 5 6 7 8 9 10

Not at

Very

6.) How much did everyone on your team contribute?

1 2 3 4 5 6 7 8 9 10

Not at

Very

7.) How well do you understand the concept of forces and how forces can be used to lift a hovercraft and push it forward?

1 2 3 4 5 6 7 8 9 10

Not at

Very

8.) How well do you understand how to create electrical circuits with switches, batteries, and motors?

1 2 3 4 5 6 7 8 9 10

Not at

Very

9.) How well do you understand the engineering design process?

1 2 3 4 5 6 7 8 9 10

Not at

Very

10.) Were you able to learn science through the hovercraft design challenge?

1 2 3 4 5 6 7 8 9 10

Not at

Very

11.) What was your teacher hoping you would learn from this experience?

12.) What was the best part about this experience?

13.) What was the worst part about this experience?