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Engaging Elementary Students in Active Learning Through Engineering – Methods, Observations and Outcomes

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Engaging Elementary Students in Active Learning Through Engineering – Methods, Observations and Outcomes

by

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Dedication

This work is dedicated to my parents, who always encouraged every wild thing I’ve ever wanted to do.

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Abstract

Engaging Elementary Students in Active Learning Through Engineering – Methods, Observations and Outcomes

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Engineering as a pedagogical tool for teaching content and driving student intellectual development is often confined to secondary school grades – middle and high school students. The goal of this work is to explore the feasibility of incorporating engineering, in the form of engineering design challenges, into elementary grade levels. The hypothesis is that engineering design challenges can be made to be age appropriate for elementary students, specifically 1st grade students, without sacrificing elements which make them effective pedagogical tools. This hypothesis was tested through the designing of an engineering design challenge for 1st grade students, which was then taught to a group of elementary students, whose responses were analyzed for desired outcomes indicating effectiveness. The design challenge was demonstrated to be engaging, effective, and feasible for the group of elementary students participating in the research. Students were observed to display engineering habits of mind, an understanding of cause and effect, systems thinking, and a basic understanding of science content through participation in the design challenge. Aspects of the design challenge which were not effective or age appropriate are discussed in this work, and recommendations for further modification of the design challenge to better accommodate elementary students is given.

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Chapter 1 - Introduction

The purpose of this report is to provide elementary educators with a theoretical framework and method for which to create authentic, engaging open-ended engineering design challenges for use in an elementary curriculum.

Much study and curriculum development has been conducted with higher level secondary students as the focus (Householder and Hailey, 2012; Sadler, Coyle and Schwartz, 2000; McCuen & Yohe, 1997; McCuen. & Kucner, (1993)). Recently, efforts have been made to create engineering curricula appropriate for elementary aged students (Donohue and Richards, 2008; Mathias-Riegel, 2001; McGrew, 2012). This report endeavors to further these efforts by beginning elementary engineering curriculum design with the end goal of impacting student's intellectual development, and developing an engineering lesson with that goal in mind.

The hypothesis for this study is that elements which are incorporated into effective engineering lessons (called engineering design challenges) in secondary school classrooms are adaptable to be age appropriate for younger students without sacrificing any of the elements which make them effective.

The report begins with a review of literature which examines what makes up an effective engineering design challenge (EDC) at the high school and middle school level, why EDCs are a valuable pedagogical tool for delivering science and math content, and characteristics that contribute to the success of an EDC at challenging and engaging students in meaningful problem solving.

The curriculum design section will address how the reviewed literature informed me as I designed an EDC to be taught in a first grade classroom. I will employ the methods and characteristics of EDCs utilized in secondary classrooms, and adapt them for first grade students. I will also discuss how the lesson will be taught by the classroom teacher, and how the effectiveness of the lesson will be assessed. The methodology section outlines the methods used to determine acceptability of the hypothesis.

The results section will analyze the data obtained through observation of the lesson taught to elementary students for evidence of desired student outcomes. The conclusion will examine the effectiveness of the EDC at the first grade level, employing secondary level methodologies at the first grade level, and recommendations to teachers and for future research into engineering in elementary grade levels.

Chapter 2 - Literature Review

This literature review will examine applicable scholarship which informs the design of an effective engineering design challenge for elementary students. The first section reviews the principle elements which comprise an engineering design challenge and distinguish it from other methods of instruction. The second section reviews scholarship on students' intellectual development and the factors which drive development. The third section reviews scholarship on design of learning environments and instructional methods which increase student learning, and relates those methods to engineering design challenges. The fourth section examines the unique needs of younger elementary students in terms of age appropriate instruction.

2.1 What are engineering design challenges?

According to the recent caucus held by the National Center for Engineering and Technology Education (NCETE) in 2012, Engineering design challenges (EDC) incorporate the following characteristics:

- Ill-structured (has a wide range of approaches and solutions)
- Affect some aspect of quality of human life
- May be resolved using approaches considered to be engineering practice ("engineering")
- Require creation or modification of artifacts or procedures ("design")
- Require learners to confront an unresolved problem in human life ("challenge")

This structure therefore mimics engineering design practiced by engineering professionals. Professional engineering practice is highly interactive (meaning solutions require teams of individuals working together to generate a solution), open-ended (meaning that no one right answer exists – there are many possible solutions, some better than others yet nevertheless acceptable), and ill-structured (meaning that solutions cannot be found by simply applying mathematics or procedures in a structured way) (Householder & Hailey, 2012). Figure 1 shows the representation of the professional engineering design process developed by Guerra, Allen, Crawford and Farmer (2012) of UTeach Engineering program.

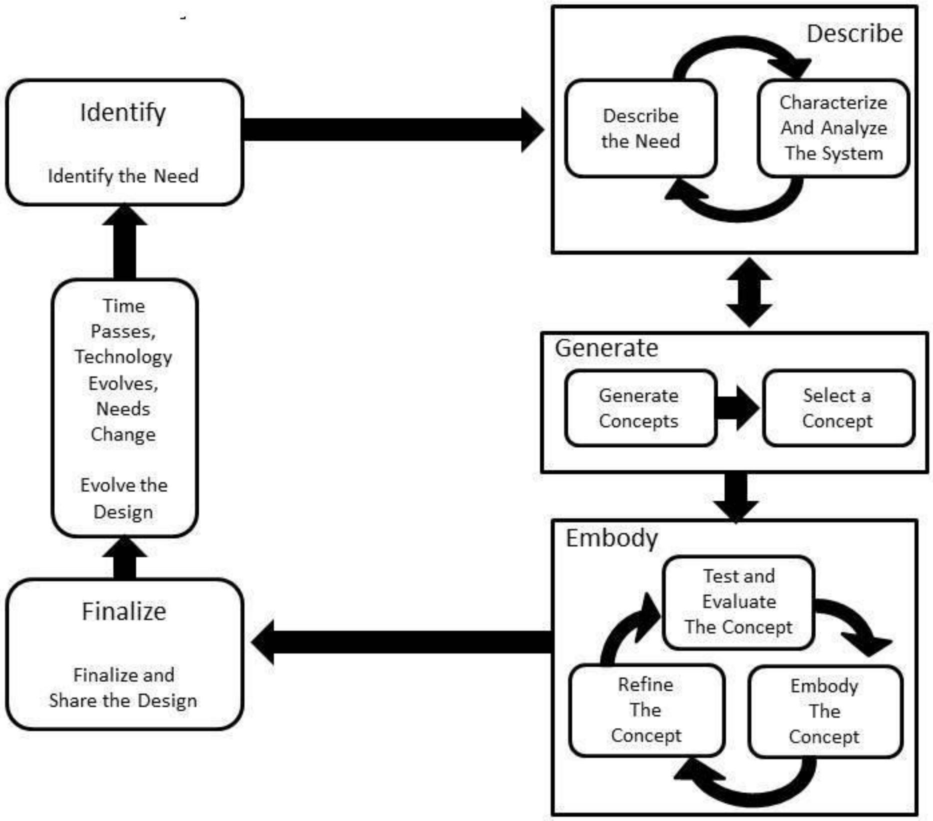


Figure 1: The Engineering Design Process

This contrasts with traditional scientific inquiry activities, which are beneficial and useful (and not applicable to discussion in this paper), but do not utilize the engineering problem solving skills. Inquiry may lead to generating and testing hypotheses, however does not involve the creation of a product or process to meet or resolve a need, and so does not fall into the category of engineering design.

Craft projects or technological design may involve the creation of a final product. However it does not require reliance on analysis of function and application of science principles in the design, and so does not fall into the category of engineering design. There are no shortage of hands-on activities for elementary students, however most do not fall into the category of engineering, because they do not involve multiple iterations to maximize performance to solve a specified problem, or are not ill-structured enough to allow for multiple paths to a myriad of solutions.

An engineering design activity must be firmly grounded in science and math principles, and design decisions should be based these principles. It should require iterations, with modifications based on analysis of testing, rather than trial and error or guessing. (Householder and Hailey, 2012)

From the NCETEC caucus report: "One Caucus participant (T. Bayles, personal communication, May 22, 2012) offered this example of an approach that could not be considered an authentic engineering design challenge:

> A teacher in our professional development group agreed to allow us to video tape a class session during which the teacher would be teaching the engineering design process. The design challenge that the teacher selected was having the students design a pinwheel – the student teams were given the identical sets of materials and a step by step instruction sheet and proceeded to construct identical pinwheels – some of the student teams finished their pinwheels before the class ended, and they did make modifications to their pinwheels – but these modifications were not grounded in any rationale from mathematics or science." (Householder and Hailey, 2012)

This activity was close-ended (there was only one solution, the pinwheel given in the instructions), did not include iterative design, modifications were not based on analysis of function, and it did not allow for variety of design solution. Therefore the activity was not designed to function like an engineering design challenge. These types of activities are quite common in elementary lessons, and it is important to distinguish them from what this paper is addressing.

2.2 Why are design challenges beneficial to student learning?

Several studies have been conducted on the stages individuals go through in their approach to viewing knowledge – a process called intellectual growth. From these studies several models of intellectual growth have been developed. A model developed by William Perry in the 1950's established 9 stages, or levels, of intellectual growth. Early levels (1-2) are dualistic, in that students view intellectual and moralistic questions as having one correct answer, teachers and others in authority know these correct answers, and their role is to impart the correct answers, with the students' role being to accept the answers without question. Levels 3-5 encompass a gradual acceptance of multiplicity of views and questioning of authorities, leading to acceptance of a lack of absolute answers at level 5. At level 6 individuals accept the need to commit to ideas or action despite uncertainty. Levels 7-9 reflect the most sophisticated view of knowledge, recognizing that all knowledge is contextual and there is a lack of absolute truth, a level which closely resembles the thinking patterns of professional scientists and engineers. Similar models of intellectual development proposed by Belensky and King-Kitchener reflect Perry's levels as well. (Felder & Brent, 2004a)

Studies by Perry and others examined the intellectual level of students entering college, and exiting college. These studies have found that most students entering college are just beginning to recognize that not all knowledge is certain, a Perry level of 3, and that on average students after 4 years of college have advanced approximately 1 level. In the words of Felder and Brent, 2004a,

> Most academicians would agree that these findings do not reflect well on the effectiveness of the subjects' college education. Rather than considering science and engineering to be mere collections of facts to be memorized and formulas to be blindly applied (as students at the lowest developmental level see them) or making superficial use of evidence to arrive at final judgments (in the manner of students at intermediate levels), the graduates should view science and engineering as processes of inquiry. When performed correctly, these processes involve using the best available evidence to reach conditional acceptance of hypotheses and models and remaining constantly open to reconsideration of conclusions if new evidence is forthcoming. This attitude exemplifies the type of thinking associated with contextual knowing (Level 5 and higher). *The implication is that science and engineering educators should adopt as a primary goal doing a better job of promoting the intellectual growth of their students than has been done in the past*." (emphasis mine.)

Social and emotional conditions both in and out of the classroom can impact student's development of intellectual growth as well. If the prevailing culture in a pre-college student's world, reinforced both in and out of school, is that teachers possess knowledge and their role is to dispense it, with student's role being to absorb and repeat it, students are not likely to develop higher level views of knowledge, and will be resistant to changing that view. Felder and Brent advocate strongly for a cultural shift that encourages independent, critical and creative thinking, accepting of intuition as a valid source of information, and challenging authorities of knowledge. "The intellectual curiosity, openness to alternative ideas, and acceptance of responsibility for one's own learning that characterize the highest levels of these models might stand as definitions of how expert scientists and engineers think." (Felder and Brent 2004b)

Sadler, Coyle and Schwartz (2000) observe that American students have a high level of knowledge of factual information, but lag behind other nations in higher level thinking in analysis of results, an observation consistent with Perry's discussed above. They observe: "Although 'hands-on' activities are touted as a way to improve these abilities, the power of these experiences is severely limited when used only to reinforce known facts and concepts. When the teacher knows the result of every activity and experiment beforehand, the prime motivating force for the student to exercise originality and explore many options in completing the activity is absent (Cohen & Harper, 1991)."

Black and William observed the following in their discussion of assessment:

> Discussions in which pupils are led to talk about their understanding in their own ways are important aids to increasing knowledge and improving understanding. Dialogue with the teacher provides the opportunity for the teacher to respond to and reorient a pupil's thinking. However, there are clearly recorded examples of such discussions in which teachers have, quite unconsciously, responded in ways that would inhibit the future learning of a pupil. What the examples have in common is that the teacher is looking for a particular response and lacks the flexibility or the confidence to deal with the unexpected. So the teacher tries to direct the pupil toward giving the expected answer. In manipulating the dialogue in this way, the teacher seals off any unusual, often thoughtful but unorthodox, attempts by pupils to work out their own answers. Over time the pupils get the message: they are not required to think out their own answers. The object of the exercise is to work out -- or guess -- what answer the teacher expects to see or hear. (1998)

The conclusion from these studies is clear - if we as a culture desire our students to have a higher view of knowledge, we will need to dramatically alter the education culture both inside and outside the classroom.

Sadler's observations of middle school students performing engineering tasks examined their intellectual development through the lens of Skill Theory – that cognitive development occurs among four tiers: reflex, sensorimotor actions, representations, and abstractions (Fischer & Lamborn, 1989). Their EDC's required the students to use a storyboard as a method for recording design iterations, test results, and reporting their findings (Sadler et. al., 2000). This required the students to operate in higher skill levels by requiring them to create multiple representations of their ideas for the underlying principles behind their designs, such as how an electromagnet works. They also observed students revising their conceptions, and eventually generalizing their ideas by applying them in different contexts. For example, while creating an electromagnet capable of lifting the most amount of weight, Sadler observes students begin to develop a conception that the current exists in the wire, and the insulation helps to guide and control the current flow, contrary to earlier notions, such as the current flowing in to the nail. They observed: "Keeping track of separate representations and using them together in a concerted way is difficult for students, but possible if they are supported in recording their findings and talking about their ideas." (P 312)

Felder and Brent's research into student's view of knowledge has led them to suggest an instructional model designed to confront students' views of knowledge and push them to higher levels, and therefore more intellectual growth. This model includes:

1. Variety and choice over learning tasks
2. Explicit communication of expectations
3. Modeling, practice, and constructive feedback
4. Student centered learning environment
5. Respect for students at all levels of development

Well-crafted engineering design challenges can incorporate all of these criteria.

1. Variety or choice over learning tasks.

This can take several possible forms. It could be as simple as directly allowing students to choose their tasks or assessments. Felder and Brent suggest these as exhibiting student choice: Predicting outcomes, interpreting or modeling physical phenomena, generating ideas or brainstorming, identifying and troubleshooting problems, formulating procedures for solving complex problems, making decisions and justifying them.

Engineering design challenges are open-ended, and so allow for almost continuous student choice over their tasks. The problem is ill-structured, allowing for multiple possible solutions. This enables students to select the course of their investigation of the problem, and they are the decision makers in how the solution will go. Generating ideas is essential to solving the problem, and students in an EDC can brainstorm individually or with a team. Troubleshooting problems is also required in an EDC, especially with multiple iterations. As discussed above, an iterative process allows students to revise their initial ideas, and hone in on a more accurate conception of the underlying principles. Students should be required to predict the outcome of their test before they perform it, and asked to explain their thinking at multiple stages of the process. EDC's incorporate virtually everything recommended for this criterion.

2. Explicit communication of expectations.

As discussed above, the necessity for clear goals is essential to an effective design challenge. In addition to goals the design must meet, such as the criteria and constraints of a product during testing, expectations for what students produce should be explicit as well. It is important to communicate to students that their grade for the project will not depend on whether their device succeeds or fails during testing. As discussed above, effective design challenges allow for multiple iterations of design, and encourage attempting ideas without knowing ahead of time if it will succeed, in order to allow students to explore and refine their ideas about how the principles at play work. Allowing students freedom to fail is essential, and so explicit communication on what and how they will be assessed enables students to feel that freedom.

The work by Sadler's team emphasized the necessity for purposeful record keeping. The models of what a design challenge is made up of as discussed by Householder and Hailey emphasize the importance of communication of results in a logical and analytical way. Both of these aspects of design challenges allow for assessment (and yes, grades) which are not dependent on the performance of the device, but rather the student's approach to the problem and analysis of what they observed. Rubrics for challenges could be focused around these aspects instead.

3. Modeling, practice, and feedback.

"People acquire complex skills—physical and mental—through practice and feedback and in no other manner, and practice and feedback are among the conditions known to promote a deep approach to learning. It follows that promoting the thinking, problem-solving, and decision-making skills that characterize high levels of development will require providing extensive practice and feedback on tasks that require those skills" (Felder & Brent, 2004b). In a design challenge involving iterative testing, students receive immediate feedback as to whether their conceptions of an idea were accurate, or require refining. Once students become familiar with how to conduct testing of a particular device, the feedback they receive then is independent of the teacher – they discover if their idea is accurate if their device succeeds as they thought it would.

Felder and Brent advocate for a collaborative environment: "An explicit goal of instruction intended to promote intellectual growth should be to demystify authority [1]—to move toward using dialogue and discovery as vehicles for learning, rather than simply providing expertise." Students engaging in a design challenge are independently developing their ideas and testing them. Students on the lower range of intellectual development may lack confidence to attempt problem solving without significant encouragement and support from the instructor (Felder & Brent 2004b). A classroom culture in which collaboration is sought from peers rather than solely from the teacher (the perceived authority) is helpful for encouraging this mentality from the students.

Felder and Brent cite the need for explicit modeling of methods and procedures for clarification, and therefore building confidence, in students at the lower range of development. The use of a teacher-created, poorly-functioning prototype, advocated by Sadler et. al., provides modeling of testing procedures, and a starting point for every student in approaching the problem, which can serve to provide this confidence boost.

"Still greater learning will occur if the students—working individually or in small groups—are given brief opportunities to figure out what to do next at several points in a worked-out example. If they succeed, they own that part of the solution; if they struggle for a few minutes and fail, they will be in a much better position to understand when the instructor does it than they would have been without the active involvement." (Felder & Brent, 2004b). As discussed above, an iterative design process allows for multiple attempts at successes and failures, promoting ownership of the solution.

4. Student centered learning environment:

Several models of student-centered learning have been researched and demonstrated.

Inductive learning – students are confronted with problems before they have all the tools they need to solve it. Design challenges require the students to generate ideas for possible solutions based on their conception of the underlying principles involved, and test those ideas for validity. Iterative testing requires them to refine their conceptions as they go.

Active learning – hands-on, active, or group work style activities as opposed to direct teach or lecturing. In design challenges, the students are essentially creating the lesson as they attempt to solve the problem, as discussed above.

Cooperative learning – students teaching other students. A cooperative learning model established by David and Roger Johnson (and applied to engineering by Karl Smith) (Johnson, et. al. 1998) outlines 5 cooperative learning criteria:

- Positive interdependence – group members must rely on each other to accomplish the goal.
- Individual accountability – Each group member is held accountable for contributing to accomplishing the task.
- Face-to-face interactions – Some or all of the work must be done together.
- Appropriate use of interpersonal skills – The challenge will require all students to work together to produce one result
- Regular self-assessment for group functioning – team members reflect on what is working well as a team, and how they could improve.

Engineering design challenges provide the opportunity for all aspects of group work to be incorporated.

5. Respect for students at all levels of development.

The use of a prototype design enables all students to begin on the same page in approaching the challenge. They all see the poorly-functioning design, and can begin to conceive of ways they may go about improving it. Students with little building experience and students with significant building experience are starting from the same place. Additionally, iterative design allows students to work at their own pace. Some teams might work quickly and test many times during the testing period, while others may work more slowly and test only 2 or 3 times. Both are tackling the problem, none are waiting for slower groups to finish, and all are free to approach it from their own perspectives. Since all the students in the same room are working on the same problem, they also have the opportunity to learn from each other as they see other students or teams testing their ideas, and observe what works and what doesn't. They are free to share what they have learned with other teams, or ask other teams questions about what they are doing.

In the pivotal work How People Learn (Bransford, Brown, Cocking, 2004), the authors identified four elements of an effective learning environment. Effective learning environments are:

1. Knowledge-centered: curriculum is focused on knowledge, and organized around core concepts that are built upon in lessons.
2. Learner-centered: focus on student knowledge and attitudes they bring in to the classroom.
3. Assessment-centered: student's thinking becomes visible to both teacher and student so it can be assessed and revised.
4. Community-centered: create a sense of collaboration among students and the community outside the classroom.

At this point it can clearly be seen that EDCs incorporate all of the effective learning environment elements as well, as they are similar to the previous discussion above.

2.3 Elements of an effective Engineering Design Challenge

Sadler, Coyle and Schwartz (2000) conducted a systematic review of engineering design challenges they had developed for the middle school classroom, in order to determine what were the most effective elements of the challenge in "increase[ing] process skills, build[ing] content knowledge, and expos[ing] children to the possibility of careers in science and technology through a range of related activities." Their findings are enormously helpful in designing effective challenges at all grade levels.

They identified the following elements of effective EDCs:

1. Clear goals. Students require clearly defined goals within which to develop their ideas about how their device will function. This is not to be confused with the necessity for the problem to be ill-structured - allow for multiple possible solutions. Even with an ill-structured problem, the criteria and constraints that the final device must satisfy are required in order to assess effectiveness of a design. Clear performance goals are essential for students to be able to understand the performance of their tests, and make future decisions about their ideas based on those results. Sadler et. al observes: "If a goal does not inspire actions that students can

evaluate from their own perspective, then they easily go astray, either detaching from the experience or defining a goal that they do understand." (p. 313)

2. Tests against nature**.** Sadler, Coyle and Schwartz's research is also relevant because it highlights the differences in student attitudes between middle and high school students. They found that the nature of design challenges that were successful at a high school level were not appealing to students in middle grades. They observed that often high school design challenges were high-stakes competitions, pitting one student's design against another student, having clear winners and losers, and requiring weeks of building with only one opportunity to compete. Sadler et. al. found this format off-putting to middle school students in general, with the tendency for students to give up before they have gotten very far, because they see themselves as behind their peers without a chance of beating them.

Instead, they approached the design of their challenges as "tests against nature" – rather than competing against other students' designs, they are attempting to create the most successful design they can through many iterations. Failed designs then are more likely to be seen as it is the idea which has failed, rather than it is the person who has failed. They observed: "Students are quite often satisfied with determining how well their new design works compared to its predecessor, with the test itself the sole arbiter." (P 313).

3. Prototype design. Sadler et. al. observed a significant difference in the performance of students presented with a prototype design prior to beginning their own design iterations, compared with students conducting the challenge without a prototype. A prototype, in this context, is a poorly performing solution to the problem presented to students prior to their own attempt to solve the problem. This approach allows students, who come with varying levels of building experience prior to the challenge, to begin at the same starting point. It allows the students to observe, even handle, an example solution, from which they are challenged to improve the design. It provides a platform for class or group discussion of which variables could be altered to try to improve the design, and even prompts students to consider varying one variable at a time to test for cause and effect.

Sadler et. al. examined this by observing two groups of students, one with a prototype design, and one without. They reported:

> Examining the work produced by the two different groups shows a difference in their ability to change one variable at a time with the prototype group succeeding in holding all variables but one constant

> for 80% of their attempts, while the nonprototype group succeeded only 53% of the time… (P. 320)
>
> Using a prototype design rather than a pure discovery approach helps to support students in working at a functional level higher than that of which they might otherwise be capable (Fischer & Pipp, 1984). Venturing into a new level of abstraction, that of discovering the scientific principles governing a device's performance, is aided by having students able to physically handle and examine concrete manifestations of their ideas. (P. 320)

Use of an initial prototype, then, seems to prompt students to a deeper consideration of the problem by giving them a starting point from which to begin to plan how to modify variables to test their ideas. I found this particular discussion in this paper quite compelling. I had previously not used a prototype design in EDCs in my middle school classroom, however after reviewing this section, I am persuaded of its usefulness and benefit to students and will strive to introduce prototypes into all future EDCs.

4. Multiple Iterations. Sadler et. al. found the structure of high school challenges in which the design only competed once to be limiting in the students' ability to discover the underlying scientific principles involved in the design. Often student designs who "won" did so through means other than mastery of the concept, such as disabling the device of a competitor (P 300). Iterative design allows students to test their ideas about how and why their device functions for validity. Because time between iterations can be short, they can get feedback right away as to the effectiveness of their idea, and revise their idea and test again. Thus students can work to develop a sophisticated idea about why their device works, and the underlying principles involved. Iterative design also allows students to work at their own pace, rather than finishing their design and waiting for the competition to be able to test it. Once students understand how to perform the tests, they can come and go as they will to test without much input needed from the teacher. (P 320)

5. Large dynamic range. Students often experience difficulty in determining what change in performance is attributable to their modification, and what is variation within measurement error. A small change in performance might lead to the conclusion that their idea was "proven", when any change observed was most likely negligible and due to measurement error. An

effective challenge therefore will require changes in performance that are large, and so it is easy to see which change had an effect and which did not.

6. Employ purposeful recordkeeping. Communication of your results is critical to engineering practice, as observed by Guerra et. al. Students often fail to connect the importance of careful note taking towards success in communicating the end result. Sadler et al. found students failed to see intrinsic value in record keeping. "Only when these records repeatedly became of use during reflective activities did we observe a gain in popularity and a serious increase in record-keeping activities." (Pg 321). An effective design challenge will require purposeful record keeping, with students able to feel the difficulties in analysis and communication of results when this requirement has not been met.

Authenticity.

Much research has been done on the need and benefit for authenticity in education. Solving authentic problems has been shown to increase student engagement, particularly of women and minorities, retention and transfer of knowledge (Wang, Dyehouse, Weber & Strobel, 2012). Wang, et. al. observe: "…it is not clear what forms of authentic engagement are contributing to these effects, highlighting the need to provide robust models and operational definitions for authentic practices. In addition, while research on authenticity and authentic practices is fully developed in science education, similar work in engineering is rudimentary." (2012)

An effective design challenge then should enable the students to feel the problem is relevant – that the problem they are attempting to solve matters in some way outside of the classroom, and it is not simply an exercise with no relevance beyond these walls. The challenge will contain authenticity if students can identify a bit of their own lives (personal authenticity), the connection of the activity to real – world problems or careers (context authenticity), the task models or resembles practices performed in real-world activities (task authenticity), or they see their findings utilized outside the classroom (impact authenticity) (Wang, Dyehouse, Weber & Strobel, 2012).

Wang, et. al. identifies factors which contribute to the authenticity of a problem:

1. Real-world context/Future professional situation
2. Complete task-environments
3. Ill-structured, non contrived problems with ambiguous data
4. Suspension of disbelief

5. Interaction among learners
6. Decision-making in practical contexts
7. Value beyond school
8. Values defensible in objective terms
9. Provide information/data that is from or mimics real-life or skills
10. Classroom-professional community balance
11. Complex problem transcending the borders defined by disciplines

An engineering design challenge can be adapted to incorporate many of these authenticity-enhancing factors. For example, data from the local power stations or city grid, or electric consumption data from a student's home could be employed to help design an energy-efficient model home in the classroom. This would connect to student's lives outside the classroom, utilize real-world data in consideration of the design, and allow for the results of the challenge to inform decisions students make at home with regard to energy efficiency and consumption.

Another method of bringing authenticity to a lesson is the practice of anchored instruction. Anchored instruction refers to the utilization of an engaging problem, often presented in the form of an intro video, which poses the problem students are to attempt to solve, and delivers information necessary to aid in solving the problem. Pellegrino and Brophy (2008) discuss in their paper on anchored instruction the use of the technique to teach math concepts by solving problems delivered in a video about a young man called the Adventures of Jasper Woodbury. For example, students employed distance-time-rate methods in order to help Jasper rescue a wounded bird using an ultralight airplane. The video presented the necessary information, such as wind and aircraft speed, then presented the problem for the students to solve. The video did this by telling a detailed story, therefore engaging student interest in the story. The problem was open-ended, there were many possible solutions, and making a solution required weighing factors and optimizing variables. There are many ways the Jasper Woodbury lesson structure could be applied to developing authentic engineering design challenges.

Jasper Woodbury presented a realistic scenario in which math skills needed to be employed. A design challenge could do the same for a math or science concept. Designing a gear system would require the application of ratios. The creek outside the school could be sampled in order to design a water filtration system to make it drinkable. A good example of engineering design with an anchor component is a book series called GoldieBlox. GoldieBlox is a story about a young girl inventor named Goldie who discovers a problem, which the reader is tasked to solve by building a device using the materials provided with the book. The book presents an engineering challenge, and the reader solves the problem to help Goldie, and moves the story along. (Sterling, 2014)

Pellegrino and Brophy (2008) observed that students often discovered while attempting to solve the problem that they did not have the necessary skills to solve it. This allowed the teacher to then scaffold in a lesson delivering the required skills. Now students were primed and ready, and already saw an immediate need for those skills as they were learning them. A design challenge can be presented in such a way that the students begin to tackle the problem without all the necessary knowledge. For example, I have developed a design challenge for my middle school classroom in which students design an airfoil and test it in a wind tunnel, to produce the most amount of lift. Students begin to work on the problem without an understanding of how a wing works. After they have tackled the problem for a while, then I hold a class discussion about how Newton's laws and Bernoulli's principle work together to produce lift on a wing. Then students revisit their airfoils and continue the challenge with the new information. Because the students have uncovered the need for the knowledge being taught, relevance and applicability are immediately apparent, and students often delight in learning a new "clue" to help them solve the problem.

Pellegrino and Brophy identified many other benefits to student engagement and conceptual learning with the use of anchored instruction, such as collaborative groups, solving similar problems using the same technique, use of technology, access to information outside of the classroom. All of which are to be found in a well-structured design challenge, as discussed above.

Assessment.

If, as Sadler et. al. suggest, the challenge should be a test against nature rather than each other, and there should be room for multiple iterations and a wide range of possible solutions, tying a student's grade on the project to the effectiveness of their solution could be innovation-killing. If students feel the pressure of their grade as being connected to how well their device performs, they will be much more likely to try something safe, fear to try something new or test out an idea, and feel discouraged when their original idea doesn't work the way they thought it would. Even offering a reward to the best performing design, such as an extra 5 points, conveys the message that the point of the challenge is to win, rather than construct knowledge about underlying scientific principles. If constructing their understanding of the concepts involved in their design is the goal, then the assessment should reflect how well they constructed their understanding rather than how well their device functioned.

A counter argument could be that not assessing the effectiveness of their design does not accurately reflect professional engineering practice – professional engineers have requirements from the customer that their design needs to meet, and the best performing device is going to be the one that gets paid. This is certainly true. But what is the goal? As a professional engineer, the goal is to apply what you know to create the best product (in order to be paid); in the classroom the goal is to construct student understanding of concepts through design. While we certainly want to relate to professional engineering practice (as discussed above), I argue that the assessment portion is not the time to do that, especially in younger grade levels.

How then to effectively assess their learning during and after the design challenge?

Sadler, Coyle and Schwartz did not include a discussion of how student learning and knowledge construction were assessed during their middle school challenges. They did make extensive use of story boards as a reflective tool, for student record-keeping and later reflection on what they changed that most effective outcome. The story board then could be a tool to teacher assessment of student learning of the concept throughout the process of the challenge, although they do not discuss the use of the story board in that way, referring to it mainly for student use.

The NCETE Caucus Report (Householder & Hailey, 2012) offers numerous suggestions for student assessment. Mainly they suggest the use of engineering notebooks and student portfolios as assessment tools. Engineering notebooks require students to carefully and comprehensively notate everything they have done to solve the problem, therefore they allow teacher insight into student thought processes and outcomes as the students tackle the problem through many iterations. An excellent tool for assessing high school student thought, but perhaps inaccessible for young elementary students. Portfolios are selected collections of artifacts of work from the students. Similar, I believe, to the story boards in that way.

For EDCs in my middle school classroom, I typically use oral presentations of findings as the sole grade for the project, an approach also advocated for in the NCETE report. Their presentations are required to include all test results, and photos, videos, or the artifact itself to help convey information. Students are assessed in how well they articulate and communicate their process and results, and convey that information to the rest of the class. The focus therefore is student analysis of their experience, rather than effectiveness of design or how "right" they were.

The NCETE report specifies that formative assessment should occur during the problem definition phase (as students are developing their plan to approach the design), and summative assessment at the end of the solution generation phase, and that assessment should be both at the individual and team levels. (Householder & Hailey, 2012). The report goes on to recommend several models for assessment of "the accomplishment of three of the goals associated with high school engineering design: improving problem solving abilities, improving student self-efficacy, and improving systems thinking capabilities." (Pg 33). These learning outcomes are targeting the skills of professional engineers and general problem solving skills – skills important for student intellectual development, but lacking a critical element in science and math classrooms: content knowledge.

Therefore, for my elementary level design challenge, an assessment piece on content knowledge must be included as well. The use of a pre- and post-test could be effective – it not only allows the teacher to assess how student knowledge of the content has changed over the course of the challenge, but the pre-test also serves to "prime the pump" on student thinking about the problem. Oral presentations or story board rubrics could also be modified to require a discussion of the principles discovered in the course of the challenge. Requiring students to write about their individual experiences will allow for individual assessment, as well as writing practice.

Developing student's intellectual skills and view of knowledge is one desirable outcome for an engineering curriculum or lesson. Additionally, the National Research Council has recently developed what are called 21st Century Skills – skills which are valuable across a wide range of jobs in the 21st century (Hilton, 2010). The role of curriculum in teaching skills in addition to content knowledge is currently being debated (Ravich, 2009; Sawchuk 2009), however the Next Generation Science Standards (NGSS) and Common Core both advocate for a shift in educational focus from solely content knowledge towards including skills development at well (Preparing, 2014; Next, 2014). 21st century skills include: flexibility, adaptability and innovation; core subject knowledge; critical thinking and non-routine problem solving; communication, collaboration and social skills; self-direction, productivity and accountability; and systems thinking (Metz, 2011).

2.4 Special considerations for elementary students

Elementary students afford unique challenges to engineering instruction due to their developmental level. Several unique considerations arise when creating a design challenge for younger students, such as: Can they write? Can they read comfortably enough that creating a list of ideas on the board for the class would be useful? Can they draw their ideas effectively? What concepts taken for granted at higher levels will need to be explained (such as negative numbers, for example)?

Elementary students, particularly 1st grade students, which are the target demographic for the lesson, are primarily concrete thinkers – they struggle with the ability to solve hypothetical problems or apply a general principle to make specific predictions (Piaget, 1995). The challenge will be concrete – the problem is in front of them, and they can immediately see results of their ideas – and so developmentally appropriate.

Students at this age may struggle with understanding cause and effect – the specific change made to a design caused a specific result. Studies have shown, however, that even young children can identify covariation of events (a change resulted in a specific outcome), and use that to infer causality. This is a basic method of determining causal relationships; simpler models of determining causality are more developmentally appropriate for younger children (Zimmerman, 2007). Therefore, elementary students should be able to base decisions on evidence at a basic level, and may be successful at drawing general conclusions on design function from their specific events. However they may still need assistance from the teacher to understand their test results and determine their next course of action.

I also anticipate an additional benefit for the poorly-functioning prototype discussed above for elementary students. Students at younger ages may have a more difficult time visualizing and manipulating objects in their heads, as described by Piaget. Having a concrete example in front of them that they can refer to can greatly improve their ability to succeed at the challenge. Sadler does identify this benefit of the prototype, however for 1st grade students this can only be even more beneficial, as they might have difficulty even understanding how to assemble the turbine blades, much less manipulate them, and the prototype gives them something they can strive to emulate during construction. The prototype should be poorly functioning, as prescribed by Sadler above, to “prime the pump” on student’s thinking about the problem and challenge them to do better. Additionally, from my own experience with elementary students, they often experience frustration when they can’t make something as well as an adult, comparing their poor drawing or building to the adult's well-made one. If the teacher creates a poorly-functioning prototype, young students might be inclined to feel more encouraged when theirs works better than the adult's.

1st grade students should be expected to be able to write words, although their command of language will be limited, especially with writing. However, as outlined above, record-keeping is essential to an effective design challenge. So the students should be expected to write about what they are doing and record test results. However the expectation for quality of record keeping should be appropriate for grade level. 1st grade students naturally tend to draw pictures to explain (Manning, 1987), which is an essential part of engineering record keeping, and should be required of the challenge. Students should be expected to record the essentials: a drawing of their design at each stage, a brief description of their idea or why they decided what they did (justification), and recording of test results.

2.5 Summary

Engineering design challenges, when appropriately constructed, can offer a powerful tool for encouraging intellectual development while allowing students to construct knowledge of scientific principles. Constructing an effective design challenge, for students of any age, requires the consideration of a multitude of features to maximize potential effectiveness of the challenge. An understanding of what constitutes an effective design challenge can enable educators to create a powerful classroom culture for pushing students into higher levels of thinking, and should be considered an important feature of any STEM curriculum of any age group.

I believe elementary students can be successful at engineering, when the challenge has been constructed with their unique developmental stage in mind. In the next section, I will describe how the aspects of an effective design challenge outline above will be applied to the creation of an engineering design challenge lesson plan for 1st grade students.

Chapter 3 - Curriculum Design

In chapter 2, I have examined several instructional models designed to increase student intellectual development and skill, and how an engineering design challenge can be employed within these models. Now I will analyze the process of applying these models toward the creation of an engineering design challenge to be enacted in a 1st grade classroom.

Distilling the information from the literature review in chapter 2, I developed the following list of elements for an engineering design challenge designed to drive intellectual development:

1. Ill-structured (has a wide range of approaches and solutions)
2. Open-ended (allow for multiple approaches for solving the problem)
3. Have a clear curriculum goal for student learning (knowledge-centered)
4. Requires creation or modification of artifacts (engineering)
5. Have clear goals and expectations for student actions and products
6. Be a test against nature rather than competition
7. Utilize a prototype
8. Allow for multiple iterative testing
9. Connect students to real-world data, problems, or uses outside the classroom (authenticity)
10. Require the use of professional engineering practices, including record keeping such as storyboards (authenticity)
11. Have a measurement range for which the effects of changing variables are easily seen
12. Incorporate an "anchor" aspect, such as a video or other engaging method of presenting the problem to be solved (anchored instruction)
13. Require students to work collaboratively (community centered)
14. Allow for opportunities for discoveries of students to be shared with other students, or the whole class (community centered)
15. Allow for feedback on students ideas, such as an easily determined successful or failed test
16. Frequent opportunities for teacher and student assessment of student progress and knowledge (assessment centered)

17. Established method for both formative and summative assessment of student thought and products produced (assessment centered)
18. Enable assessment of student learning through artifacts or story boards (assessment)
19. Assessment examines content knowledge

These elements should be applicable to a design challenge at any level. These will act as my guidelines for developing a design challenge for the 1st grade classroom.

3.1 Developing the challenge.

A goal for this report is to provide elementary teachers with an easily implementable method for design challenges in their classrooms, and as such I was interested in creating a design challenge for this classroom that required few and relatively inexpensive materials, with little set up, but could allow for as much variation on design solutions as possible, and allow the first grade students to be able to perform the tests without much help needed from the teacher (allowing independent multiple iterative testing with immediate feedback on idea performance).

A relevant and pressing societal problem in the area of science, and also a topic covered in many science standards, is that of sustainability and conservation. So I began by researching products 1st grade students could build, which would allow for iterations, related to sustainability. I considered many sustainability related artifacts, such as a greenhouse and water filter, both of which could make excellent design challenge, but eventually settled on a wind turbine generator.

There are already several curricula available online about wind turbine design. KidWind (Exploring, 2014) is a set of wind turbine design curriculum which includes all the materials for wind turbine design challenge and teacher resources. KidWind provides several levels of wind turbine design, a mini kit, a basic kit, and an advanced kit. One kit ranges from about $40 to $140, or can be purchased in class sets for several hundred dollars. Effectiveness of a KidWind turbine can be measured by voltage output, how much weight the turbine can lift, or how much water a pump powered by the turbine can pump. KidWind also has a large network of outreach, educator workshops, and lesson plans around the concept of wind power generation.

One interesting aspect of the KidWind curricula is the online competition. Teams can work to improve their designs, and submit their results to an online competition. This is intriguing because it encourages innovation and multiple iterations on turbine design, even after the lesson is finished within the classroom. It does turn the design challenge in to a competition among students, however some students will find this motivating, even if some do not.

I was unable to determine through their website the intended ages of KidWind lessons. All the photos on the website were older students, probably middle and high school, which seems consistent with other resources available online. KidWind is a compelling resource for elementary projects, provided the school has the resources to procure the equipment.

NASA also has a turbine design lesson for 9th through 12th grade available online (NASA, n.d.). The NASA lesson provides detailed teacher reference for how wind is created and how wind turbines make use of wind energy to create electricity, and is an excellent resource for teachers on the principles governing wind turbine operation. The pdf also provides an introductory lesson on convection, and provides a template for students to record designs and results. However the lesson is not a test against nature – the object is to declare one team the winner. The lesson as written also does not encourage multiple iterative testing. The lesson plan suggests adjusting blades, but does not specifically call for teams to repeat testing multiple times with adjustments based on test results, recoding each iteration. It also does not include a prototype design.

Another wind turbine lesson came from the non-profit community group EFMR Monitoring. This group produced a series of lessons about wind power for elementary through high school grade levels (Epstein, 2009). One elementary lesson has students create "something" to catch the wind. Their "something" is not tested or quantified on its effectiveness at catching the wind, and it is not iteratively tested, but it does have the open-ended and ill-structured aspect to the problem. Another lesson has students build a pinwheel, but the students follow directions and there is no variation in design.

PBS and the US Department of Energy produced a lesson plan for 9th – 12th grade wind turbine design challenge in which students have an open building time to build and test as often as they like during the building window (Fetters, 2010). The ultimate goal of the testing is to determine a winner by conducting a final test of turbine designs, and suggests awarding bonus points to the student with the most effective design. Students do have a chance to test iteratively prior to the final test. It also does not make use of a prototype and does not require students to record test results. It suggests students write a paper for assessment.

None of the wind turbine challenges I found online incorporated the use of a prototype design. As discussed above, the use of a prototype appears to be highly beneficial for younger students, so I will need to incorporate that in to my wind turbine challenge for 1st grade.

	Strengths	Weaknesses
KidWind *Middle and High School*	• Many variations of lesson design • Large network of educator support and professional learning community • Online competition – extends lesson beyond classroom • Could be adapted to elementary level	• Materials are expensive and consumable • No prototype
NASA Wind Turbine Design Challenge *9th – 12th grade*	• Detailed and comprehensive teacher background information • Introductory lessons included • Provides template for recording test results	• Competition • Does not encourage multiple iterations • No prototype
EFMR Monitoring *Elementary*	• Open-ended lesson • Hands-on building	• Does not test device or quantify performance • Not designed to solve a specific problem • No multiple iterations of testing • Pinwheel lesson does not allow for variation in design
PBS and US Dept. of Energy Wind Turbine Design Challenge *9th – 12th grade*	• Open building time allows for multiple iterations • Includes a summative assessment at conclusion of lesson.	• Competition style lesson with bonus points awarded to best performing design • Does not require recording of test results

Figure 2: Summary of sample wind turbine curricula

3.2 The lesson plan

The lesson plan was constructed by systematically addressing every item on the list above. Here I will discuss each list item and how it was addressed in the wind turbine design challenge lesson plan.

1. Ill-structured (has a wide range of approaches and solutions)
2. Open-ended (allow for multiple approaches for solving the problem)

The problem I created for the 1st grade students is this: How can we create a wind turbine that will produce the most amount of power? This problem statement contains no restrictions, and provides no guidance or suggestions for solutions, and so is open ended and ill-structured, the first two requirements on the list I compiled for an effective design challenge. The only constraints placed on student solutions are those imposed by the test stand itself – their turbines will need to fit on the test stand, and the blades must attach to a cork so that the turbine can easily be installed and removed.

3. Have a clear curriculum goal for student learning (knowledge-centered)

This lesson was created to fit within a classroom unit on energy and conservation, however, the research study ended up being conducted at a Cub Scout resident camp. The theme of the camp was construction, and other activities the students participated in during the camp were focused on sustainability, conservation, and recycling, and so the wind turbine challenge fits well with the goals of the camp. A wind turbine contains many possible variables for design, such as: blade shape, blade pitch, number of blades, blade materials. The results of a particular turbine design are easily measured by use of an inexpensive multimeter. Students, particularly in Texas, may have seen wind turbines before and so can relate to them in a real world context. It also connects to a discussion of renewable versus non-renewable resources for creating energy. Additionally, students will observe electricity actually being created. Young students are familiar with the fact that electricity comes out of the wall outlet and they use it for everyday tasks, but they may lack the sense that the electricity has to be produced somewhere outside of their house. This design challenge will help them to understand that electricity has to be generated somehow, that there are many ways it can be generated, and they can see their own creation generating it and being used to do a function (such as power a light bulb).

(It is true that power is not the same thing as voltage. Power, in electrical engineering terms, is the product of voltage and current, and therefore will depend on both things. However, this lesson was created for 1st grade students with a lack of understanding about what electricity is. The distinction therefore between power and voltage is less important. I believe it is more important to have an easily quantifiable method of measuring turbine effectiveness, which can be quickly explained to students. Therefore I believe measuring voltage in order to quantify turbine function will suffice for the purposes of this challenge.)

However the aspects of wind turbine function the students will be interacting with the most involve manipulation of the blades and how the wind will interact with them. Therefore, students will be engaging more with the mechanical motion of the turbine rather than the electricity it generates, so this design challenge would fit well with a unit on forces and motion as well.

4. Requires creation or modification of artifacts (engineering)

The challenge requires students to construct a wind turbine which they attach to a generator, with wind simulated through use of a fan. The wind from the fan will turn the turbine blades, which turns the generator. The generator is attached to a multimeter which will measure voltage output. More voltage indicates more electricity being produced, and therefore a more effective turbine design. (Diagrams of the test set up are provided in Appendix 1 to this report).

There are many variables in turbine design which the students can manipulate, as discussed above. The materials for the turbines are inexpensive enough that students can build a new turbine for each iteration, rather than disassembling the old one to create a new one. This allows students to preserve each iteration, and see how their idea has progressed over time, even return to older ideas if their progression was unsuccessful.

5. Have clear goals and expectations for student actions and products

The lesson plan asks the teacher to demonstrate a prototype prior to allowing students to design their own. There are many advantages to the use of a prototype, as previously discussed, but it also demonstrates procedures, how to actually build a device, and expectations for testing results, as prescribed by this item on the list. Students of this age may struggle with motor skills for building their device, such as attaching the blades to toothpicks using tape. Having the prototype reference allows students to see an example and attempt to mimic it.

During the prototype stage of the lesson plan, the teacher also demonstrates how to use a story board to document results, and introduces the expectation that students document each design iteration and test result during testing phase. The teacher will also monitor student documentation during testing. The teacher is asked to inform students that the story board will be used to explain their results with the class and with the teacher at the end of the lesson.

6. Be a test against nature rather than competition

The goal of the design challenge is to create a wind turbine that will create the most amount of power, as measured by voltage produced when the generator spins. Because assessment of effectiveness involves an easily determined number, with big being "good" and small being "not as good", students will no doubt compare their results to other teams to see whose is bigger. It is a natural part of group dynamics, and unavoidable. However, the lesson is designed not to emphasize comparison between groups but rather to compare each test to the other tests within a student group. There are no rewards, or even recognition, for the best performing turbine in the class. There are no negative consequences for a failed tests; in fact, the lesson plan encourages failed tests as evidence of what doesn't work, and as a basis for making changes in the future. The lesson plan encourages the teacher to establish a culture where failed tests are valued, rather than discouraged.

After each team has completed testing, the class shares their results with the other teams, with the goal of using everyone's individually gathered knowledge of what makes an effective turbine in order to work together to create one "best" turbine design. The class compiles their experiences into a list of what design features the best turbine must contain, then that turbine is constructed and tested. So the culminating event is collaborative rather than competitive.

7. Utilize a prototype.

The lesson plan requires the teacher to create and demonstrate a poorly-performing prototype, and even recommends features it could contain that would make it perform poorly. However, if it is made too poorly, it won't turn at all, and so won't demonstrate how the voltmeter displays voltage. So, it must perform poorly, but not so poorly that it doesn't turn. The prototype is then used to challenge students to "make one that works even better than mine", demonstrate how the voltmeter works, how to conduct a test, and how to construct the turbine. The lesson plan prescribes that the teacher keep the prototype available for students to examine and handle both before and during testing. I believe this will be essential for the younger students, especially that they are able to handle it, since they have difficulty at that age manipulating objects in their mind, and benefit from concrete examples in front of them.

Additionally, the lesson plan recommends a prototype test result document. The lesson plan prescribes the use of story board documentation recommended by Sadler's article. I have modified the story board to make use of a material 1st graders are familiar with, story paper (this modification is discussed further in item 10 of this list). The lesson plan recommends teachers document test results for the prototype design during demonstration, utilize the story paper to document these results, and prominently display this prototype test document for students to reference during testing.

8. Allow for multiple iterative testing.

After the prototype is demonstrated and the challenge explained, the students are free to design and test and their own pace. The materials are made available, and the test stand is left for students to use when they are ready. I believe the test procedure is simple enough that, after students have performed a test with assistance once or twice, they will be able to do it on their own, without help from the teacher. Therefore, students are free to test as often as they like.

The only limitation to this is the fact there is only one test stand. The lesson plan recommends teachers consider purchasing multiples of test stand items, so they can build several test stands. This will allow for the possibility of students conducting even more tests, because they will not have to wait for other teams to finish before they can test.

9. Connect students to real-world data, problems, or uses outside the classroom (authenticity)

The lesson plan seeks to engage students in real-world application of principles through a discussion on electricity and how it is produced prior to introducing the challenge. It begins with a discussion on where electricity comes from, and how it has to be created in a power plant before it can be transmitted to your house. The lesson plan then calls for introducing photos of "real-world" wind turbines, some of which students have seen before, and a discussion of their similarities and differences.

10. Require the use of professional engineering practices, including record keeping such as storyboards (authenticity)

As discussed in the literature review section of this paper, engineering notebooks are effective, however not practical for 1st grade students. For the 1st grade challenge, I decided to use the story board method recommended by Sadler, Coyle, and Schwartz. The story board will provide a structure to record keeping that is chronological, and logical, and serve as a reminder for the students to keep track of their designs and test results as they go along.

However, for the 1st grade students, I felt they would need even more structure than the story board designed for middle school students, due to their limited writing and drawing skills. So for this lesson, I added additional structure in the form of a box for students to draw their ideas, and a structured place to record the results of testing they decided to do. Figure 3 shows the story board I designed for 1st grade students to track their results. The teacher would prepare the story board structure, one per each student team, and the students would use it to document results during the challenge. The story board should be on a poster board so it is large enough for students to work with, and can contain multiple cells for many iterations.

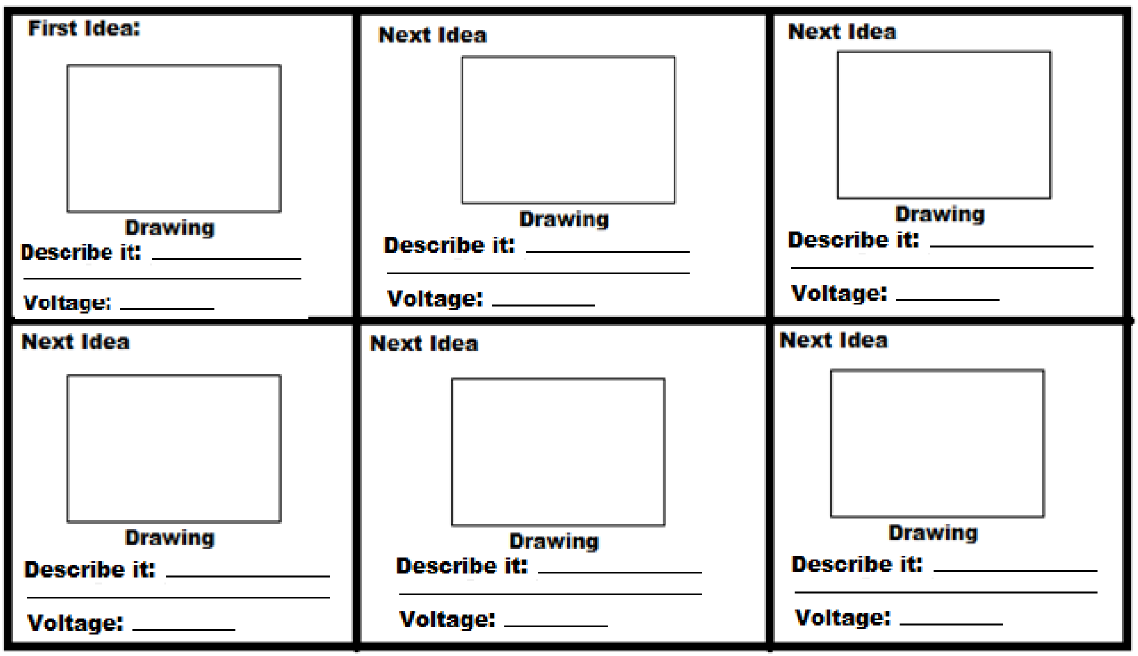


Figure 3: Elementary level storyboard

An alternate conception would be to use a common 1st grade writing paper, called story paper. Story paper is familiar to 1st graders, and has an area on top for drawing and an area below for writing. Students could use the story paper to record their designs and test results, then tack the paper in the appropriate story board cell as they go along to create the story board. This makes use of a familiar paper, and requires less preparation on the teacher's part. The 1st grade classroom in my case study will use the story paper option, due to their young ages.

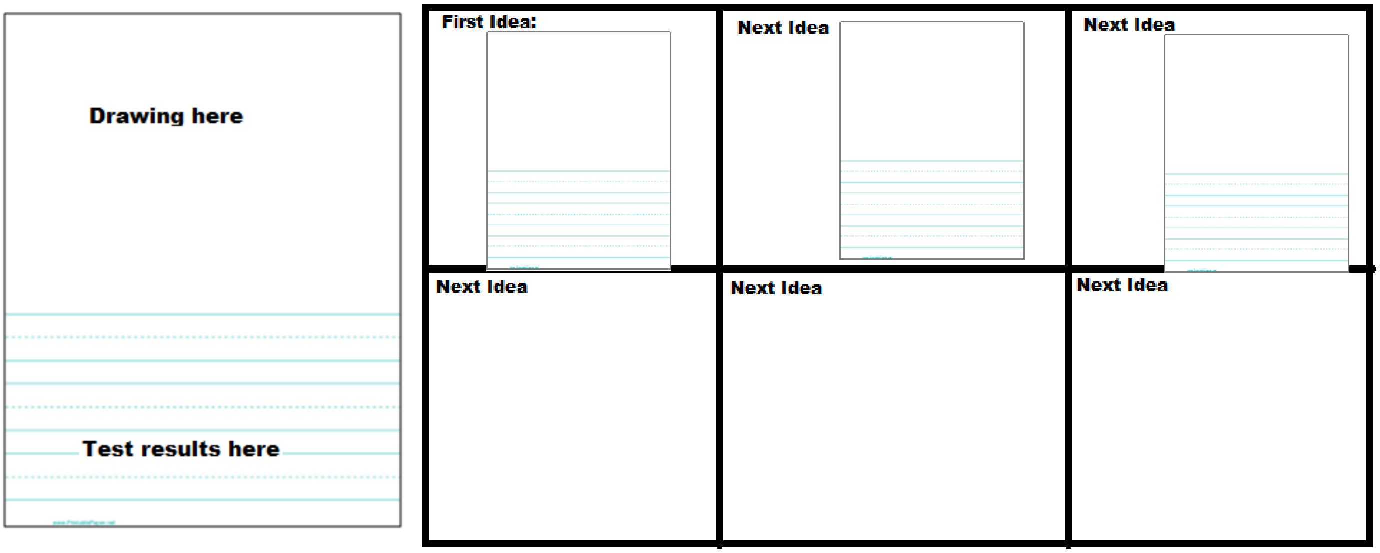


Figure 4: Story paper and its use on a storyboard

11. Have a measurement range for which the effects of changing variables are easily seen.

The design of the testing set up will allow for a clear demonstration of a failed idea because the turbine will not rotate, so students will get no result. If the blades have no pitch, they will not rotate. The voltmeter, when set to the 2V setting, will display 3 decimal points, so changes in performance should be easy to determine.

However, the voltmeter function may present some challenges for younger students. The reading on the voltmeter will bounce up and down; students may have difficulty determining what to write down. I believe that with the younger students a simpler solution would be better, and recommend they write down the largest number they see. This also provides an opportunity to discuss how real world results don't often work out as nicely as we would like; an elementary-friendly discussion of ideal versus actual results.

Additionally, younger students may lack comfort in dealing with decimals. The most likely result for this test set up will be voltages that are smaller than one volt. Students will need to be reminded that larger numbers mean better performance than smaller numbers, and 0.4 is bigger than 0.2, just like 4 is bigger than 2.

Depending on how the students set up their turbine design, they may encounter readings with a negative voltage. Positive and negative voltages indicate direction of current flow, and a negative reading simply means their turbine is turning in the opposite direction. Therefore, negative and positive voltages can be directly compared to each other, since it simply indicates direction of rotation. So it would be safe for students to disregard the sign and look only at the number.

12. Incorporate an “anchor” aspect, such as a video or other engaging method of presenting the problem to be solved (anchored instruction)

The lesson’s opening discussion begins with the teacher telling the students the battery on their cell phone is dead. What do we do when that happens? This leads to discussion of where the energy coming from the wall came from.

13. Require students to work collaboratively (community centered)
14. Allow for opportunities for discoveries of students to be shared with other students, or the whole class (community centered)

The students are grouped into pairs for this challenge. Each pair works together to produce turbine designs to test, and creates one story board to document results. Therefore student pairs are required to collaborate with each other.

After the testing is finished, the lesson plan has the students share their results with the rest of the class. The student pairs present their story board to other student pairs and describe what they learned about turbine design. After each team has shared their results, the teacher leads the class in determining the features that would make the best turbine design possible, based on what each team has learned. The teacher compiles a list on the board, then the class works together to build the “best” turbine design. When it is built, the students test it to see how it performs.

This forces the individual teams to collaborate with each other as well, and turns the challenge into a collaborative effort in which the whole class succeeds together. Each team learns about turbine design on their own, and then shares their specialized knowledge with the class in order to contribute to the whole class effort. This also reflects collaborative efforts in “real world” situations such as the way a work place functions with specialized individuals contributing to the success of the whole.

15. Allow for feedback on students ideas, such as an easily determined successful or failed test

The wind turbine lesson utilizes one test stand that students can bring their turbine designs, place on the stand and perform the test. I predict that students, even younger 1st grade students, after having performed a few tests with assistance, will be able to perform tests on their own, without assistance. This enables the student to test as many times as desired. The lesson plan also recommends constructing multiple tests stands, if the materials are available, which allows for simultaneous testing, and therefore the opportunity for more tests to be accomplished during the testing window.

The success of the turbine is determined by reading the voltage produced by the turbine from a voltmeter. As discussed above, students may struggle to understand the decimals and negative numbers on the voltmeter. Therefore interpretation of the test result may require some coaching from the classroom teacher.

16. Frequent opportunities for teacher and student assessment of student progress and knowledge (assessment centered)

The building and testing phase allows for frequent and constant feedback from the teacher, other students, and from testing performance.

17. Established method for both formative and summative assessment of student thought and products produced (assessment centered)
18. Enable assessment of student learning through artifacts or story boards (assessment)
19. Assessment examines content knowledge.

The goal of any classroom activity is to teach students a specific content goal. The goal of an engineering design challenge is to do that by allowing students to discover the underlying principles governing how their device functions, through iterative design and testing. So it is important to determine what principles the students will be discovering through their design.

There are many scientific principles at work in a wind turbine: conservation of energy from kinetic energy in the wind to kinetic energy in the turbine to electricity in the generator; generator action and how electricity and magnetism work together; Newton's laws governing forces and motion. Many of these concepts, while vital to making the wind turbine function, will be inaccessible to 1st grade students.

The concept the students will be working with the most, although they will not be aware of it, is forces and motion and energy conservation. In order to maximize turbine performance, the students will need to maximize the amount of kinetic energy (KE) in the wind that is transferred to KE in the turbine, and minimize energy lost to other sources such as bending of the turbine blades. Additionally, the most effective turbine designs will have a strong pitch to the blades (blade angle with respect to the plane of turbine rotation), probably somewhere close to 45^o or so. This is because the wind, traveling towards the turbine perpendicular to the plane of rotation, needs to transfer its energy into motion of the turbine blade along the plane of rotation, 90°. Newton's 3rd law of motion will apply here – if the turbine blade is angled so it pushes the wind downward, the wind will push the turbine blade up, therefore causing the turbine to spin.

1st graders are not likely to reach a sophisticated knowledge of these principles through this design challenge; this level of understand would be more appropriate for a high school classroom. Therefore, assessment must look for the beginnings of understanding about energy conservation (that energy from the wind makes electricity to do a job), and forces and motion (the wind pushed the blades to make it turn).

The final phase of the lesson asks students to share their storyboards with the class, then compile each team's discoveries into one list of the features of a good wind turbine. The teacher should be looking for the features of rigid blades and pitched blades in student discussions, which are key components for the concept goals for this lesson. This will also allow students teams who did not see those features themselves to now learn it from another team. The class then uses this list to create the "best" wind turbine, based on the class-identified criteria, then tests it. This phase allows the teacher to assess the learning of the class as a whole on the topic.

Each team created one storyboard, which can allow the teacher to assess the team's experiences, problem-solving, and ultimate conclusions from the challenge.

The final event of the lesson as prescribed is for students to write a paragraph about what they learned about electricity, how it is produced, and what makes up an effective wind turbine. Having each student write a paragraph allows the teacher to gain an understanding of what individual students have learned from the challenge. Since we have two specific concepts in mind for this challenge, students' paragraphs should be guided to address what they understand about these two concepts. Questions should guide their written responses, such as: What does a wind turbine do? What makes a wind turbine good at doing that? What would a good wind turbine look like?

Another excellent method of assessing student understanding is to require them to apply their understanding of turbine design in a new context. Airplane propellers use a similar design to their blades to perform their function, and so require students to use their understanding of forces. Most forms of electricity generation require a source of energy to turn a generator. Even a coke can Hero engine uses the same principle to make the can spin as the wind making the turbine spin. A discussion or paragraph question for elementary students could require them to identify the source of energy for turning the generator in other energy sources, such as a dam or steam turbine, and asking students to find what is similar among these seemingly different objects assesses transfer of concepts from one context to another.

An extremely important facet of engineering challenge assessment is not to tie a student's grade for the project to their device performance. This would remove the test-against-nature aspect and return the challenge to being a competition among peers, which, as discussed in chapter 2, can be a hindrance for younger students (Sadler, 2000). It would also communicate to students that a failed design equals failure to meet expectations for the project, rather than foster the environment that failed tests communicate valuable information and should be embraced. If grades must be assigned for the challenge, it should be related to student documentation, problem solving approaches, and final paragraphs or communication of findings.

Chapter 4 - Methodology

Once the design challenge curriculum was developed, what remained was to allow elementary aged students to interact with the lesson in order to test the hypothesis. The hypothesis for this study, as discussed in chapter 1, is that elements which are incorporated into effective engineering lessons in secondary school classrooms are adaptable to be age appropriate for younger students without sacrificing any of the elements which make them effective. Therefore it was necessary to perform a research study in which elementary students are observed performing the lesson in order to attempt to determine if the lesson was age appropriate and desired student outcomes were achieved from the engineering lesson.

The sample for this research study were the elementary-aged students at a Cub Scouts Summer Camp. All participants were Cub Scouts, male, ages 7-9. The lesson was conducted during a 3 day resident camp during the summer, in which participants stay overnight during the camp. The wind turbine design lesson was one of the rotation stations the cub scouts visited during the camp. The lesson was conducted during three 45-minute sessions during the 3 day camp, one on each day. The data was collected during 2 weekend resident camps of the same structure. Week 1 sample contained 7 students who were observed, week 2 sample contained 18 students.

The sample naturally organized into 3 distinct groups. Because fewer cub scouts were present during week 1 of camp, all the students ended up in the same group throughout the camp. Week 2 contained more cub scouts, so the students were split into two groups throughout the camp. For this study, I will refer to the students from week 1 as group 1, the first group from week 2 as group 2, and the second group from week 2 as group 3.

Group 1 and 3 had a similar makeup of student demographic, mostly Caucasian, with parents with mostly white collar professions. Many parents reported design-intensive occupations such as engineer, software designer, or architect. Group 2 was made entirely of bilingual students, most of which spoke primarily Spanish at home. Parents in group 2 reported mainly blue collar professions, and spoke little to no English.

Due to the setting of this study, students are already self-selected to be higher than average in terms of experience with building projects. Most students were self-identified as either high or medium level experience with building projects on a demographic questionnaire. Additionally, students have a high level of parent involvement, since their parents accompanied them to the resident camp. Many parents in attendance identified themselves as having a high-skill occupation such as engineer or architect. Therefore the student population during the study was skewed towards an affinity for engineering, simply by the setting in which the study was conducted.

Recruitment of the teachers for the study was conducted by the Cub Scouts camp. The Cub Scouts camp uses volunteers of all ages to implement its program. An adult teacher was assigned to teach the lesson, with two youths assisting. One of the youths, a 4th grade girl whom I shall refer to as Elizabeth, naturally began to take over the teaching of the lesson over time, and eventually became the main teacher. She acted much as an adult teacher would, asking questions and eliciting desired results, and the students reacted to her much as they would a teacher, due to her positional authority as a member of the camp staff. So I consider her a teacher for this study rather than student.

The instrumentation used during this study consisted of two types of interviews: informal interviews conducted with students as they were working on the lesson, and more formal, one-on-one interviews conducted with individual students and teachers after the conclusion of the lesson. Both forms of interviews were audio recorded. There were not previously selected interview questions for the informal interviews; the interviewer instead asked students questions only to elicit their verbalization of their thinking while working on the lesson.

The formal interviews were conducted with randomly selected individual students, during lunch, immediately after concluding the lesson. The formal interviews used the following questions as a guide. Each interview was tailored to specific students and their experiences during the lesson, so not every question was asked of every student.

1. Can you tell me about what you did in the lesson?

   This question is designed to get the student to reflect on what they did during the lesson, and elicit their initial thoughts about the lesson they had just finished.

2. How did you feel about the lesson?

   This question is designed to get them to reflect on their feelings about the lesson. Was it frustrating, or fun, or disappointing, etc.

3. Tell me more about what you did or did not like about the lesson. Can you be specific?

   This question is a follow-up to the last, to move from more general feelings to specific aspects of the lesson.

4. What does this lesson have to do with science (or the concept taught)?

This question is designed to assess their opinion about how this connects to science content knowledge. Additionally, students may interpret the question to refer to science professional practices, which is also an outcome of the lesson.

5. Was it hard to do this lesson? What was hard about it?

   This question is also attempting to elicit specifics about their experience in the lesson.

6. Would you like to do a lesson like this in the future? Why or why not?

   This question is designed to elicit thought about what the students positively gained from the experience; to ask them to reflect on what they got out of the lesson that they would like to do again.

7. Do you think it was valuable to look at what other kids were doing?

   This question is addressing collaboration and sharing of ideas among students or groups of students

8. Was it helpful to record what you did on the posters we made?

   This question is addressing the specific engineering practice of purposeful record keeping. Did they gain an understanding of the need to record results for its intrinsic value, rather than because the teacher said you need to.

9. Do you think what you learned in the lesson is useful? How could you use what you discovered outside your classroom?

   This question is geared towards transfer of knowledge, either content knowledge or professional practices.

The teachers were also formally interviewed at the conclusion of the lesson, in order to gage their impression of the value of this type of lesson for their students. Teachers were interviewed during lunch following the conclusion of the lesson, and were audio recorded.

1. How well do you think the lesson went in your classroom?

   Much like with the student interviews, the first question is designed to allow the interviewee to reflect generally on the lesson and what occurred.

2. Do you feel the content and structure of the lesson was appropriate for the grade level of your students?

   This question asks for the teacher’s opinion as to how well an engineering lesson had been adapted for younger students, either content-wise or the actual performing of the building and testing and interpreting results.

3. How do you feel this lesson impacted your students?

A general question asking the teacher to consider the impact of the lesson on students in a similar way that this study is considering it. It is vague to allow for a variety of ways the teacher could interpret impact.

4. Are there any barriers you anticipate for you in being able to implement a lesson like this on your own?

   This question is targeted for elementary classroom teachers, to explore their comfort level with type of lesson structure. It was eliminated from the interviews of the youth teacher, Elizabeth

5. Would you deliver a lesson like this in the future?

   A general closing question to allow the interviewee to consider the broad application of this type of lesson in their own classroom practice. Again, it was not asked of Elizabeth.

Additionally, photos of student artifacts and storyboards were collected. Artifacts were selected randomly, but generally it was attempted to collect photos of high achieving artifacts and average artifacts.

4.1 Procedure

This study is compliant with the U.S. Department of Health and Human Services Code of Federal Regulations, 45 CFR § 46.102(2009). This study is deemed to be one of minimal risk to participants and that the probability and magnitude of harm or discomfort anticipated in the research will not be greater than any ordinarily encountered in daily life, or during the performance of routine physical or psychological examinations or tests. The study was conducted under the oversight of the Institutional Review Board of the University of Texas, study number 2014-03-0077. Student confidential data, such as anything containing identifying characteristics, was kept in the possession of the researcher at all times while on site, and kept in a locked file cabinet when not in use. Students in this report are referred to using alias names.

Participants were recruited from the available pool of cub scouts attending the resident camp that weekend. The research study was described to parents and students during the registration portion of the camp, during which time parents and students were given the consent and child assent forms included in Appendix 2 of this report. Parents and students were asked to review consent forms and sign them when they came to the first class several hours later.

Parents remained on site, and most participated in the lesson with their students. The lesson plan is contained in Appendix 1 of this report.

Day 1 consisted of four 45-minute sessions with 2-3 students in each session. During this session, the lesson was introduced generally to the students. The teacher then led a discussion designed to provide context for the wind turbine challenge. The teacher asked students about electricity and what powers devices at home. The teacher discussed different forms of energy, and the fact that wind moving constitutes energy. The teacher showed the students photos of several different types of "real-life" wind turbine designs, and asked the students to identify what is the same and what is different about the different type of turbines. This discussion is designed to provide context, and also to get the students to begin to consider the design elements that make "real-life" turbines work. The photos also remained out during the following sessions to allow for reference.

Following this discussion, the students were introduced to the test stand, the prototype turbine, and the voltmeter. Students were introduced to the vocabulary words such as voltage, blade, and hub. The fan was then turned on, and the students observed the prototype, and the reading on the voltmeter. The teacher then told the students their job was to build a turbine that will work even better than this one (get a higher reading on the voltmeter). The students were then shown the available materials for building their wind turbines. Lastly, students were shown how to keep record of their designs and test results using the storyboard. At this point students were released to begin building. Because the pool of students was broken down into four groups, each session only had a few students. Therefore each student worked alone, rather than in partners as the lesson plan prescribes.

During day 2, all students were collected into one group, and all did the session at the same time. Day 2 consisted of a 45 minutes session in which students built and tested wind turbine designs. There was one test stand, so students took turns coming up to test when ready. Students continued to work individually, since most had started the day before and were in different points of the building and testing process. The 4th grade staff teacher, Elizabeth, positioned herself at the test stand to assist the students during testing, asked them questions and pointed out aspects of their test result, and reminded them to write down their results on the story paper. At the conclusion of day 2, the students' storyboards and designs were collected and retained for the next day.

Day 3 consisted of all the students in one group, and was a 70 minute session. The students were given 20 minutes to finish building and testing their designs, and recording their results. After that time expired, the students sat in a circle around a table. The students took turns showing their storyboard and presenting the "story" of their designs. After all students has presented, the teacher asked the students to generate a list of features that would make the "best wind turbine ever". The teacher wrote the list on a poster for everyone to see. The teacher then asked the students to help her build the "best wind turbine ever", and then tested it on the test stand. Students were then invited to take their storyboards and wind turbines home if they wanted. After the conclusion of the lesson, the students ate lunch, and some formal interviews with students and teachers were conducted.

Week 2 of resident camp was conducted in same manner, with the same schedule. The context discussion day 1 was modified to focus more on the concept of energy from the wind being converted into electricity by the wind turbine, and to include more discussion on the design of the "real life" wind turbines in the pictures. Additionally, students remained in two different groups during week 2, rather than converging into one group as in week 1.

4.2 Data processing and analysis

Student outcomes for this lesson were evaluated against the desirable intellectual development outcomes discussed in chapter 2. The data collected during the study was qualitative, and consisted of audio recordings of students during the lesson, and formal interviews with selected students and teachers after the lesson concluded. Student responses were then analyzed utilizing the following threads:

1. Evidence of utilization of professional engineering practice
2. Evidence of 21st century skills
3. Evidence of understanding of cause and effect
4. Evidence of content knowledge
5. Student Communication
6. Transfer of knowledge from one context to another

Professional engineering practice was chosen because students mimicking the habits of professional engineers is a desired outcome, as discussed in Chapter 2. The same is true for 21st century skills. Cause and effect and student communication are included in discussions of 21st century skills, however they were identified explicitly because both are essential skills in the field of science and engineering (Next 2014, Householder & Hailey 2012), and therefore I desired to analyze the data for those skills explicitly. Student ability to successfully apply concepts used in one context to a different context is called transfer, and can be used as an indication of deeper understanding of the concepts learned (Wiggins, 2005).

Transcripts of audio recordings and observations was then analyzed utilizing qualitative analysis software for the 6 threads above.

4.3 Validity

The setting of this study was unique in that it occurred at a Cub Scout weekend summer camp rather than a typical classroom. The environment in which the lesson was delivered mimicked a classroom environment – indoors, with one adult teacher conducting discussions with students at a table – but deviated in some significant ways. Because the students are there only for the weekend camp, they do not have a relationship with the teacher. The teacher has positional authority, much as a classroom teacher does, but the students and teacher have not had time to develop rapport. The students come from a diverse background, and not much is known about the students prior knowledge before their arrival for the lesson. There has not been an opportunity to establish classroom norms. Also present during the lesson were other youth staff members assisting with the lesson. They have positional authority due to being a staff member (easily identified by bright orange staff shirts), but are closer in age to the students than a teacher would be. Additionally parents were on site during the camp, and in some cases worked alongside their students during the lesson. Frequently parents were observed asking their students leading questions, much as a teacher would, but the quantity of one-on-one discussion time with individual students would not occur in a classroom with one teacher. The structure and administration of the lesson was similar to a typical classroom, but other factors in the environment were not.

Therefore, the results of this study are generalizable to all elementary students to some extent. The thinking patterns and problem solving abilities of the students are a function of their age, and so how elementary students approach this type of problem can be generalized to students of this age. Similarly their motor skills in actually building the device as students will be varying developmental stages, much as they would be in a classroom, despite their shared Cub Scout experience. This study is not generalizable to a classroom setting due to the differences discussed in the previous paragraph.

Chapter 5 - Results

This chapter will present my analysis of qualitative data collected during the two iterations of the lesson performed during the two Cub Scout Resident Camps. The data will be analyzed against the six themes identified in chapter 4: evidence of utilization of professional engineering practice, evidence of 21st century skills, evidence of understanding of cause and effect, evidence of content knowledge, student communication, transfer of knowledge from one context to another. Transcripts of audio recordings were imported into a qualitative analysis software, and individual responses or exchanges were coded by each of the six themes, and if it represented a "good" example or a "poor" example of the theme.

Figure 5 shows percentage of student responses coded into the six themes.

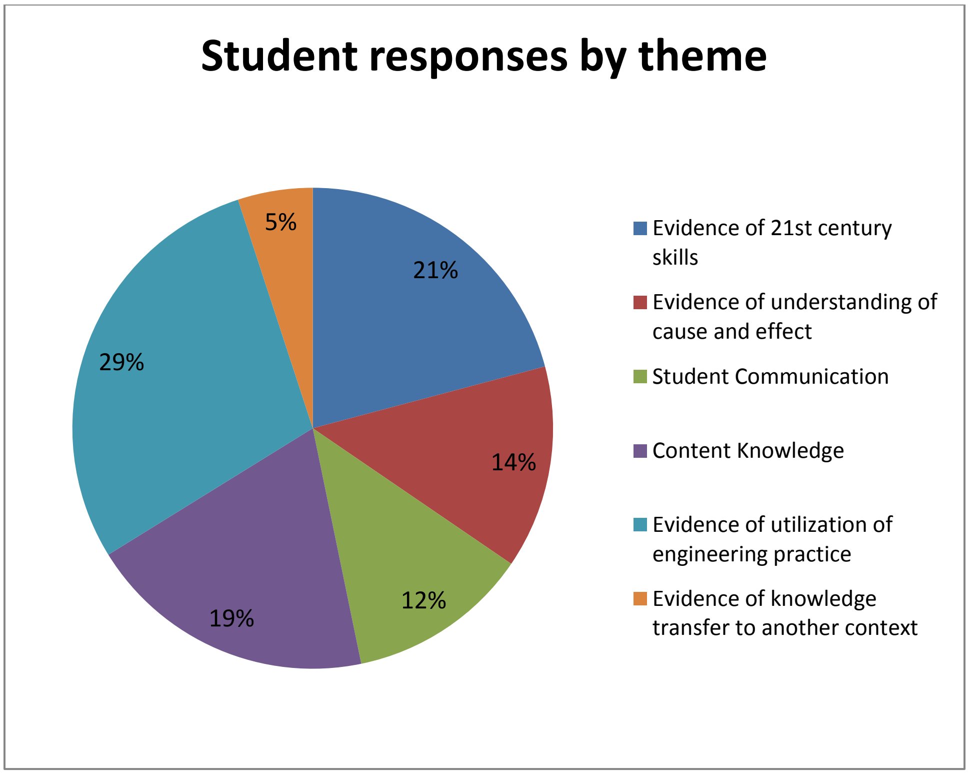


Figure 5: Student responses by theme

Changes between week 1 and week 2

Because of the iterative nature of this study, I was able to modify the lesson plan between week 1 and week 2, due to reflection on the lesson from week 1. The opening context discussion was modified to focus on only 2 things: energy transformations from kinetic energy in the wind to electricity in the generator and eventually to the plug in your home, and the similarities and differences in wind turbines designed to do the same thing. During week 2 I attempted to have students work in pairs, and to have a structured building and testing time in which students all build one, then observe as everyone's design is tested, then build another and test as a class, and so on. Neither these changes ended up occurring – students continued to work individually and test whenever they were ready. Additionally the story paper was removed from the storyboards for week 2.

I also shifted my approach to interacting with the students during building. I made a point to frequently reference both the prototype and the wind turbine pictures when discussing their designs, forcing them to compare what they are doing to other designs. For example, I would show the prototype and ask "The prototype has 3 blades. Do you think it would better with more blades? Less blades?" etc. I also shifted my questioning during building to a focus on uncovering cause and effect. During the opening discussion week 2, I attempted to incorporate a bit of an anchor problem in that I asked what I would do if my cell phone battery was dead. Why would I plug it in to the wall? What comes out of the wall? Where did that energy come from? And so on.

5.1 Professional engineering practice

The data were examined for evidence of engineering habits of mind being displayed by the students as they progressed through the lesson. Habits such as effective record-keeping, use of evidence or test results as a basis for design decisions and modification of designs based on evidence.

Justification for design decisions

As shown in figure 5, student responses coded as "evidence of justification for design decisions" was the largest group of student responses, 40 individual responses of a total of 187 analyzed. Of those responses related to justification of design decisions, approximately two-thirds showed students were able to articulate the basis for their decisions, and approximately one-third were unable to do so, as shown in figure 6. This demonstrates that a majority of students across all groups were able to discuss justifications for design decisions when asked. A majority of students were able to articulate justifications when asked most of the time.

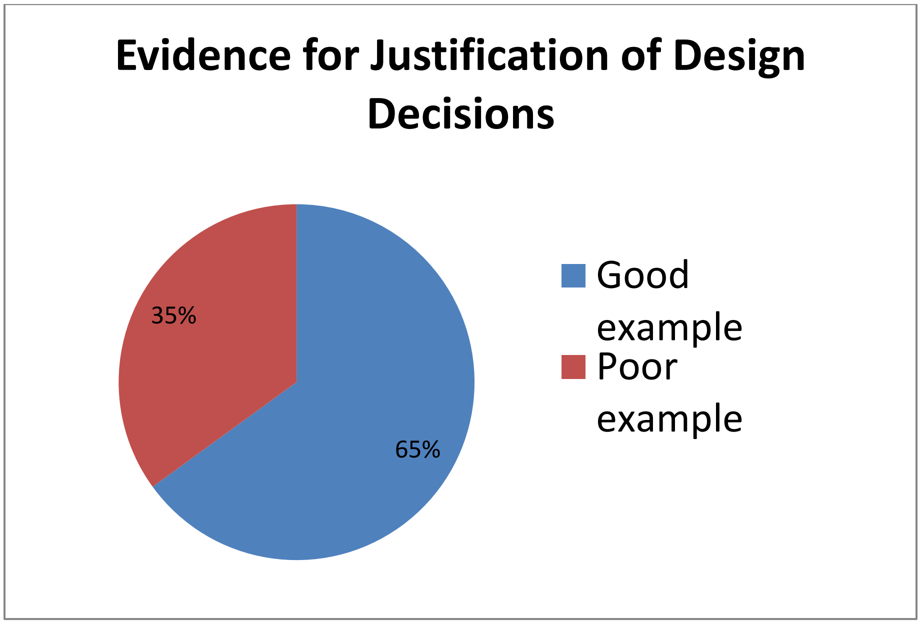


Figure 6: Evidence for justification of design decisions

Some students had difficulty articulating their reasoning behind design decisions due to difficulty in language. This is especially true of the students in group 2, for whom English is not spoken at home. But students in groups 1 and 3 also displayed difficulty in communicating their ideas. Often clarification of their responses had to be sought by the teacher. For example, in this exchange below, the student, whom I will call Anthony, was discussing his design ideas while building.

> Teacher: How many blades, what do you guys think?
>
> Anthony: um, 3.
>
> Teacher: Ok, so the same as the prototype had? 3? Why do you like 3?
>
> Anthony: Because I think like, they do more energy with 3 blades.
>
> Teacher: Why do you think it will be more with 3 blades, than with like 4 or 12?
>
> Anthony: It's too much
>
> Teacher: It's too many? Why?
>
> Anthony: Because… its more hard to do than 3.

The student was unable to communicate his decision to make one with 3 blades in a way understandable to the researcher, however the student does appear to have an idea behind for his decision.

However, as shown in figure 6, about one-third of responses displayed a lack of justification for design decisions. A majority of students observed initially began building with no plan, preferring to grab materials and start building right away. This is behavior expected from students of this age group, and is not necessarily counter to engineering habits of mind. However some students were observed to make design decisions with no justification well in to the building process. The most common response when asked about design decision was "I don't know". One student responded "it just kinda came to mind." And another "I just like 3 blades" and "cause I just want it I guess." Intuition can be an acceptable starting point for engineering challenges, especially with students of this age. However some students were observed to be unable to articulate a rationale for design decisions well into their building process.

An interesting exchange occurred during the concluding discussion for group 3, when students were asked to create a list as a group of what the "best design ever" would look like. The students were debating how many blades their "best" design would need. Elizabeth led the discussion and recorded their consensus on a poster. She went around the table soliciting the opinion of each student individually. The students volunteered 2, 4, 5 and 9.

> Teacher: I have a question. Kids who said 2, why do you think we should use 2?
>
> Alex: Because it goes fast.
>
> Teacher: Because it goes fast. Why do you say that? Do you have evidence to support that?
>
> Greyson: Because when I used that, that went the best.
>
> Teacher: That was the one that worked best for you?
>
> Greyson: mmhm.
>
> Tom: The one that worked best for me, went into the 200s, was with spoons and 2 blades, so that's how I got mine.
>
> Charlie: I don't think 2 is good, every time I used 2, I got [unintelligible]
>
> Teacher: Ok. Kids who said 5, why'd you say 5?
>
> Alex: Because 5 would be more simple!
>
> Kevin: That would be heavier.
>
> Teacher: And I don't think anybody did any tests with 9 blades. So it seems to me like 2 blades is the only suggestion we've have where we actually have evidence to say yah, 2 blades is good.

Elizabeth: So are we going to use 2 blades, or 4 blades?

[they all started yelling]

Elizabeth takes a vote again.

Elizabeth: ok, we had a tie between 2 blades and 4 blades.

[She takes another vote.]

Elizabeth: 4 blades was the total.

Tom: That wasn't a tested one! It wasn't tested!

Teacher: You guys who argued for 2 blades you made a great case, but 4 won the vote.

Tom: 4 blades wasn't tested.

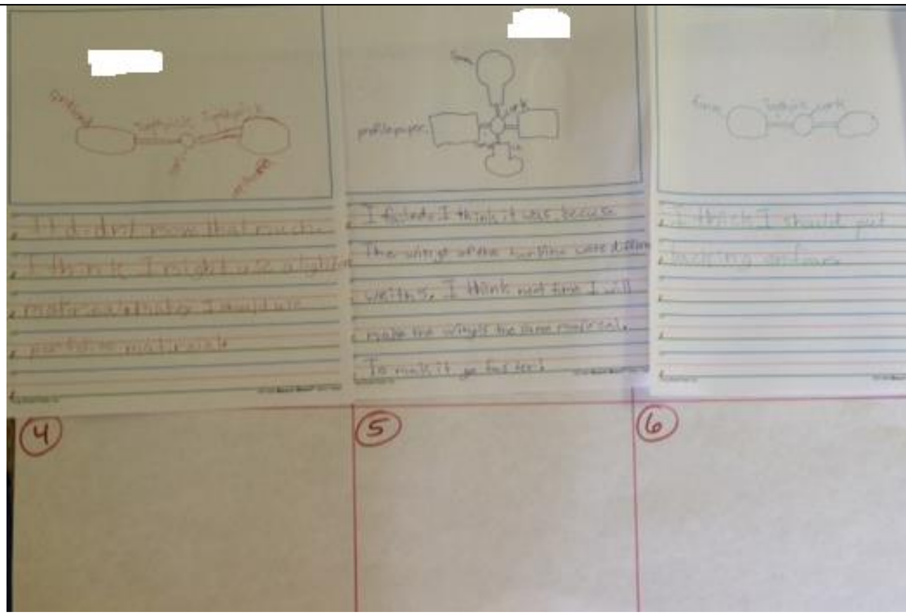
Initially the students volunteered responses with no justification from their experience. Once it was suggested to use test results as a basis for making decisions at this point, the students enthusiastically embraced the idea, to the point that Tom refused to accept the consensus vote because he did not see any evidence to support it.

Record keeping

A difference between week 1 (group 1) and week 2 (groups 2 and 3) camps was how the students were asked to keep track of their results. Both weeks used the storyboard method, however during week 1 students were asked to record their results on story paper, then tack their papers onto the storyboard posters. During week 2 students were instructed to draw and record results directly on the storyboard poster. This modification was made in order to reduce the amount of lose paper in the room, and so minimize some of the chaos during building and testing.

There was a distinct difference in how well the students recorded results. Storyboards made using story paper tend to include much more information than the groups who did not use the story paper, who tended to write down only the numerical result, if that. Perhaps having the lines on the story paper encouraged the students to write more, rather than leave empty lines. It should be noted that week 1, which utilized the story paper, also included more parent involvement. It is likely that the increase information recorded in week 1 compared to week 2 is a result of parents reminding and encouraging students to record more information.

Week 1 storyboards



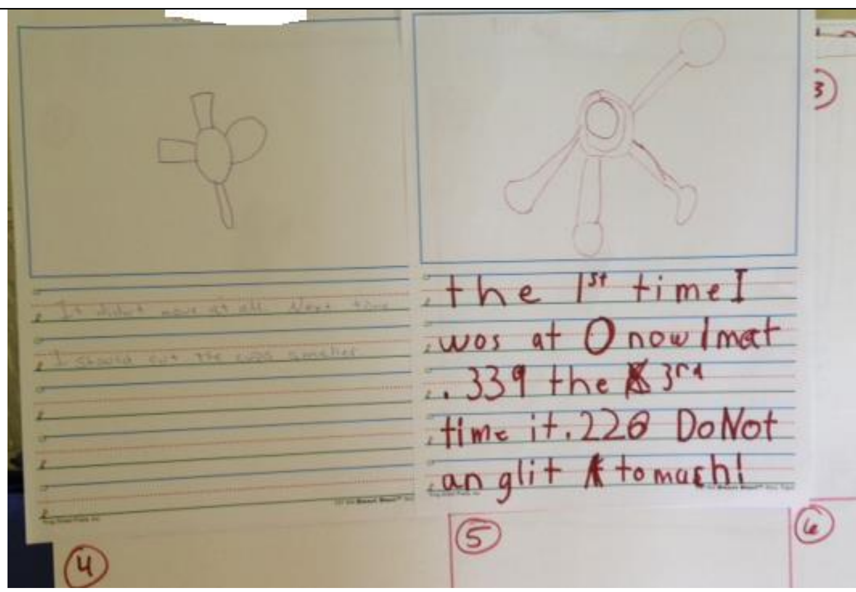


Figure 7: Student-created Storyboards

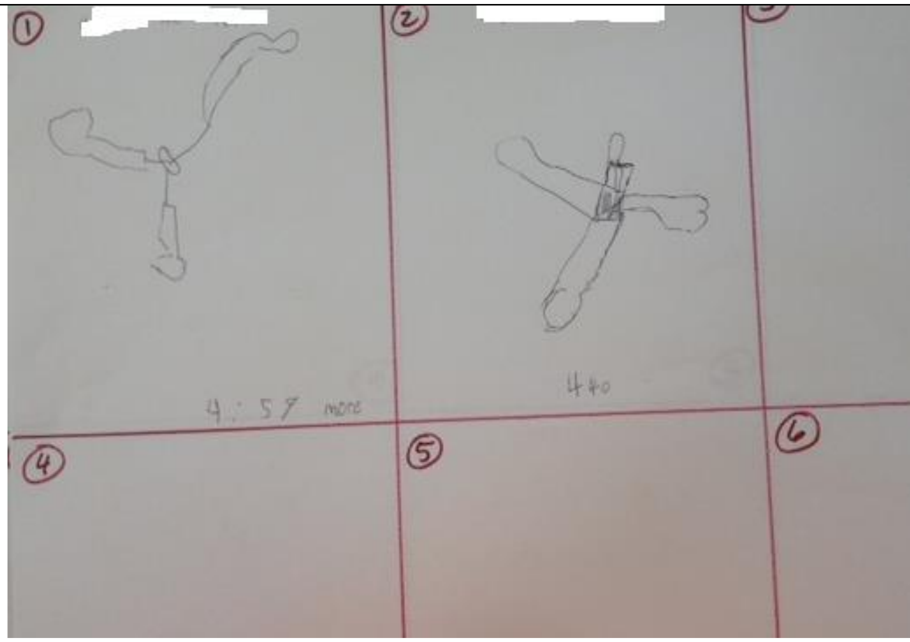
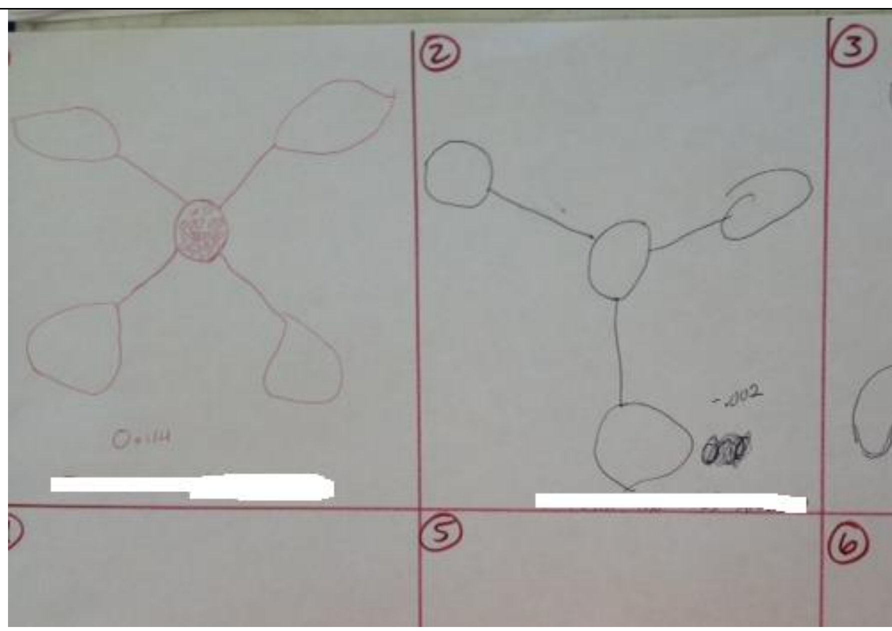
Week 2 storyboards



Figure 7: Student-created Storyboards

Even though students in week 1 recorded more information, it was not always useful information. The following example shows a student who filled the story paper with writing, but most of what was recorded are opinions and celebrations of creating a design that functioned, rather than recording observations.

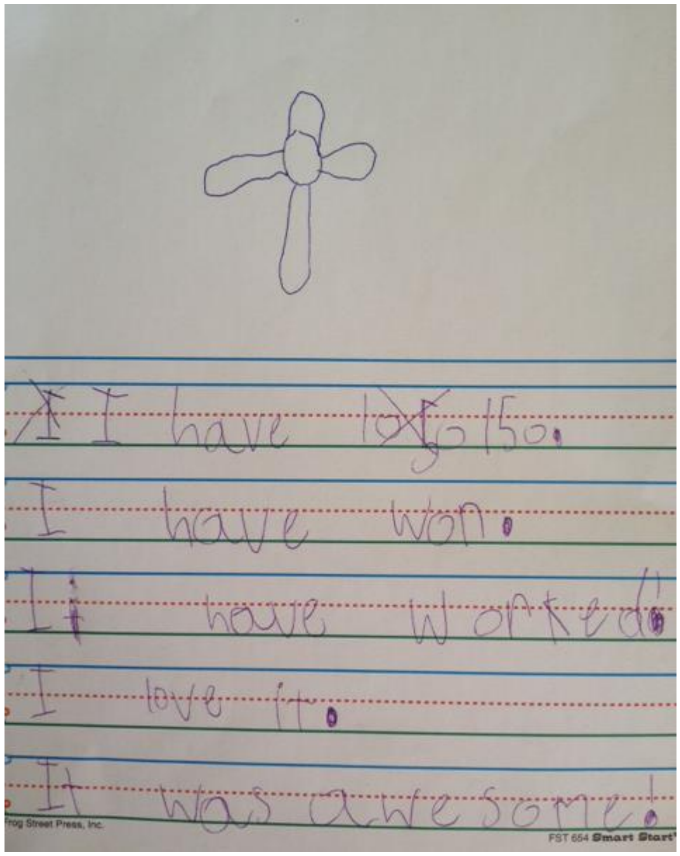


Figure 8: An example of student record keeping

Not surprisingly, the students were naturally not inclined to record their test results, and required reminding practically every time they tested that they were expected to record their results. However, students who were interviewed after the lesson reported that recording their test results helped them remember what they did, and helped them share their results at the end. During presentations one student simply read aloud what he had written on his storyboard. Another student neglected to record one of his tests, and could not remember what it looked like, but reported that he believed it was his best one, as he tried to recall from memory the numerical result. The presentation time at the end helped them see the value of recording their results.

One particular difficulty students had was with the decimal values the voltmeter reported. As predicted, students at this age are unfamiliar with decimals, and were inconsistent in reporting them in their results, even inconsistent in either recognizing or ignoring them. The following are several quotes from students discussing their results.

- "And the third one it went to 2.80 and then it went to 104. And then it could've went to 504. If I did the plate one."
- "And the other one got 124 and it wasn't working until I moved one then it started to move. And the other I did was 2.60 and it broke."
- "It was 8.50 but it was supposed to be .850."
- "When I used the spoons it got 4000"

In general students understood what to look for in terms of a "good" test result – larger number is better. However the difficulty came when students had to write down or report the numbers; their lack of facility with decimals led to inconsistent usage. Most students ignored the decimal and recorded results in terms of hundreds, but for some students this was especially challenging.

Additionally, students were unfamiliar with the concept of voltage. This was addressed in the opening discussion with students, where voltage was introduced as a way to measure how much electricity was flowing. However once students began to work with the numbers, they were unable to use the term. Many students reported the number as a speed, saying "It got a speed of ___". Another student referred to the number as "G's". The teachers repeatedly used the term voltage, however the students never gained any facility with that term. No student was observed to use that term on their own.

Open-ended design

The students were observed to initially approach the process as one of uncovering the "right" answer. Even other staff members (youths), when observing the lesson, asked what the "best" material was to use. When asked this, Elizabeth (the 4th grade staff member helping teach the lesson) hinted that she knew the answer but wouldn't tell, because she had observed the spoons to be effective the day before.

However, the "best" turbine discussion at the end of the lesson, for all 3 groups, shows spirited debates over which material to use for the blades, and number of blades - differing opinions on what is "best". This is suggestive of the loosening of the concept of one right answer for the best turbine design.

5.2 21st century skills

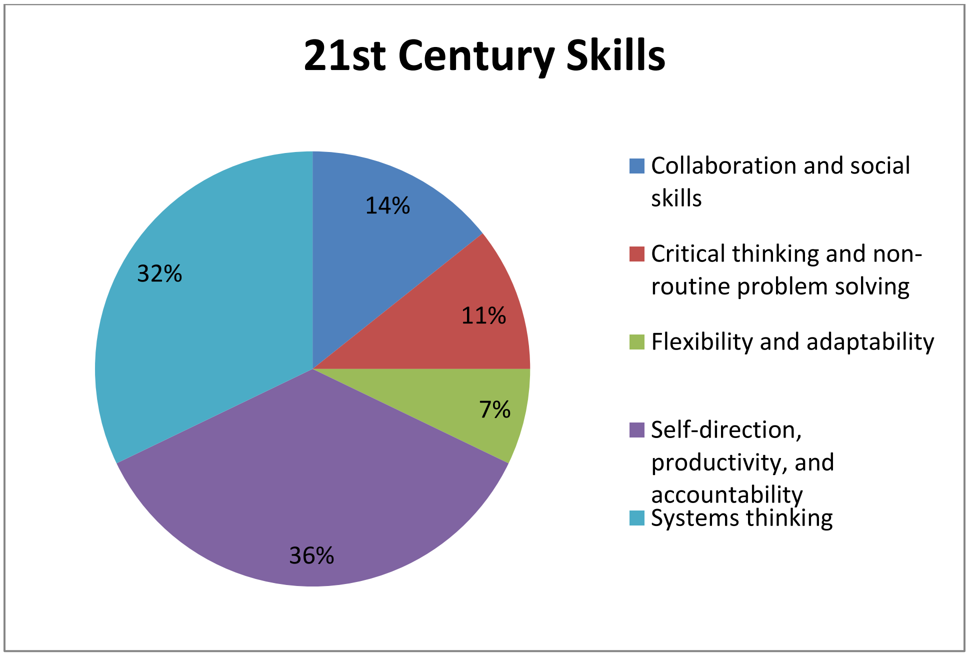


Figure 9: 21st Century Skills

The most commonly observed skill listed under "21st century skills" was that of self-direction, productivity and accountability. Many students were eager to begin the building, and already had ideas in mind prior to being released to build. During the "best" turbine discussion during week one, Scott repeatedly asked if he could draw out what it should look like, because he had strong opinions and wanted to show them through the drawing. After the discussion was over and the group worked together to build the best design, Scott remained at a different table, drawing and beginning to build his idea.

When assisted by adults, students were frequently observed utilizing systems thinking to approach the problem. On several occasions, parents were observed visualizing with their student which way the wind would hit the blade, and using that to determine how to best position the blade. Students were rarely observed to perform these visualizations of the wind and its effect without prompting from adults, either parents or teachers. The following exchange is one example of students visualizing how the wind will affect the turbine.

Teacher: Which way did you bend it?

Tom: This way.

Teacher: So the cup [of the spoon] is facing this way now [away from the wind]

Kevin: Maybe you should bend it the ooottther way.

Teacher: Why? Where's the wind coming from?

Tom: Thiiis way [turns spoon around to face the wind]

In this example, Kevin is assisting Tom to visualize the wind and how it will affect his spoons. Often students used their hands to mimic the invisible wind and which direction it is moving, attempting to visualize it. This is a more abstract form of thinking, traditionally difficult for students of this age.

The lesson was originally written for students to perform the challenge in pairs, however the first week contained so few students that the students performed it individually. During week 2 students were asked to perform the challenge in pairs, however they all ended up doing it individually on their own. So the collaborative nature of an engineering design challenge was diminished significantly. However students were observed to collaborate a bit by helping each other out or offering suggestions, as in Kevin's example above. Additionally, as discussed previously, the entire class had to collaborate during the "best" turbine discussion.

Students were adept at examining what other students were creating and modifying their own designs based on other's test results. During both weekends, most student designs became variations on number and placement of spoons as blades, as they saw their peers have success with spoons. One student whom I will refer to as Scott, began on day 1 to do an interesting exploration of using cups for blades. He discovered that the whole cup was not effective, and began to cut them in half and tape them to toothpicks when time ran out for the day. The next day, he completely abandoned the cup idea and picked up spoons, because he saw most of the other students working with spoons and having success, despite the fact that he was working towards a successful design with cups. Teacher Elizabeth remarked that the teachers needed to encourage more variation in designs, such as Scott's cups, as most students were using spoons.

5.3 Evidence of understanding of cause and effect

This theme had the second highest occurrence in student responses, at 21% of responses.

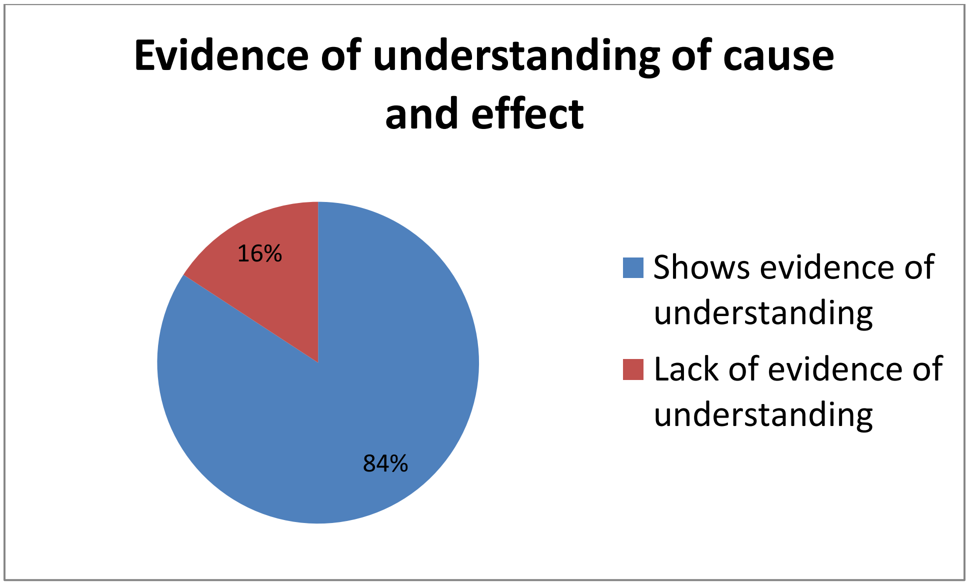


Figure 10: Evidence of understanding of cause and effect

As shown in figure 10, the majority of student responses indicated an understanding of cause and effect, indicating that generally students were able to connect specific outcomes of their designs to specific changes they had made when asked. Students were frequently observed to be discussing weight ('it's too heavy" or "that's too light"), and how pieces of their designs had run into the test stand, and that is why their design wasn't spinning.

The following are exchanges in which students show facility for interpreting cause and effect.

> Teacher: So what happened. It wasn't working and then…
>
> Gregory: Then when I moved the fin, it started moving…
>
> Teacher: Moved it how? What did you do to make it work?
>
> Gregory: I twisted the fins a little bit and it started moving.

> Teacher: Change the shape? Did you notice what happened to blades when we turned on the fan?
>
> Henry: Yah it bent!
>
> Teacher: So maybe the paper is not great?
>
> Steven: Yah we need to make it stronger.
>
> Henry: Make it cardboard.

Teacher: Ok, nothing happened.

Charlie: I don't know, it's not moving.

Teacher: Why do you think it didn't work?

Charlie: I don't know why. It's not moving because I don't have anything that is pushed on and catching it and blowing it back.

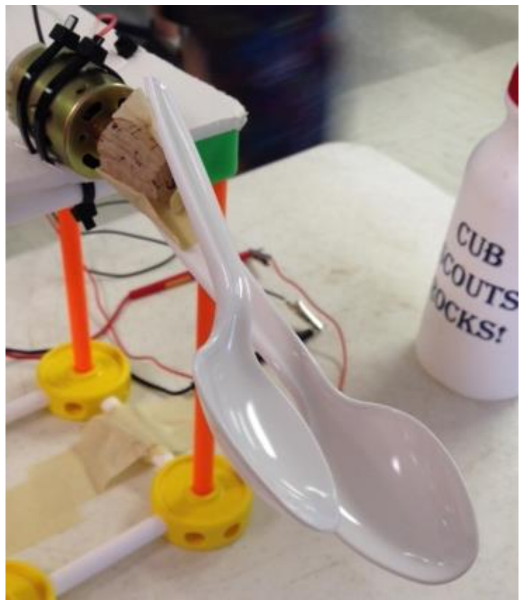


Figure 11: Charlie's first design – the spoons are pointed into the wind instead of perpendicular, and therefore will not "catch" the wind

As shown in figure 10, a relatively small number of student responses indicated difficulty with understanding cause and effect. Most of these responses were students in group 2, for whom English is not spoken at home. Therefore it is possible that students were unable to successfully articulate cause and effect relationships they may have had an understanding of.

For example, one student, whom I will call Alejo, created a wind turbine with 10 large blades made of paper. Initially the blades were turned so they were perpendicular to the wind, and so it did not turn. I showed Alejo the photo of wind farm turbines, and asked him questions to lead him to notice that the blades were angled with respect to the wind. He then angled the blades, and when he tested, the turbine spun relatively quickly and generated a relatively large amount of voltage. I then observed the following conversation.

Teacher: So what did you do that made it work?

Alejo: I don't know.

Teacher: Well what did you do this time?

Alejo: I just put paper, and put tape… and tape…

Elizabeth: Do you think maybe the size?

Alejo: …on the thing, to not fall down.

Teacher: Elizabeth just mentioned the size, they're really big, and also look, they're tilted. So the wind pushes on them. When it was flat, it wouldn't work, but when you tilted it, it spun around.

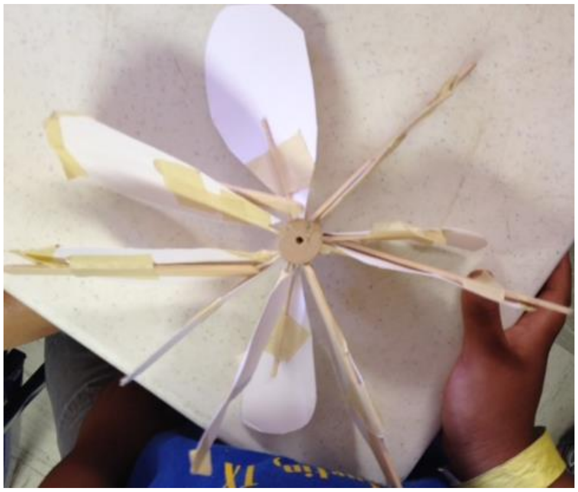


Figure 12: Alejo's design

Alejo was unable to articulate a connection between his action and the more favorable test result, despite our earlier conversation about angling the blades. During testing, some of his blades had fallen off, and since in this exchange he is talking about tape and "not fall[ing] down", it is possible he was focusing his attention on this problem rather than the reasons for the more successful test result.

When Tom attempted to angle the blades on one of his designs, the tape ripped, so he decided to forgo angle in favor of structure (as he put it), and it did not spin. I discussed with Tom how sacrificing the angle made it not work. During sharing of results at the end of the lesson, Tom reported that when he didn't tilt the blades, it didn't work, repeating almost exactly our earlier conversation. This supports the conclusion that the students needed assistance in order to fully understand their device and results.

5.4 Content knowledge

Student responses coded as an example of correct usage of underlying science concepts most commonly referred to discovering the need to angle the blades in order to get their turbine to spin in a circle. The next most common concept discussed was the need to make the blades light weight and strong. Students frequently reported choosing a material because it was light. Students also discovered the need to have the blades “catch” the wind, and this reason is the most frequently reported reason for choosing spoons as a blade material. Therefore students are developing and displaying facility with the idea that the wind pushes, or puts a force on, the blades, the spinning of the turbine is a result of the force from wind, and the blade will move in the direction it was pushed.

More student responses were coded as examples of incorrect content usage than correct, however most of these were due to incorrect use of terminology, such as referring to the numerical result as speed rather than voltage. One student consistently referred to the numerical result as “G’s”. He was repeatedly reminded the result is voltage, and I had a discussion with him about what “G’s” are as a unit, which he insisted he knew already, yet continued to use the term when discussing results. Towards the end of testing, he was beginning to use the term “voltage”, yet still struggled with wanting to say “G’s”.

During the “best” turbine design construction, Jason had a very strong opinion that the turbine blades should be angled, however he believed they should be angled in alternating directions, which would not be effective. He was unable to articulate why he believed this to be the best, but he was intent on alternating the blade angles. He understood the need to angle the blades, but his understanding was incomplete, and led him to a false conviction. He had not had enough time to fully understand the relationship of blade angle to turbine performance. More building and testing time would be needed for him to fully understand the relationship.

Few students connected the numerical result to electricity without prompting, despite the context discussion at the beginning of the lesson. This is most likely due to the student’s lack of familiarity with the concept of electricity, and the terms involved. A few students from group 2 mentioned they thought it would produce more energy when discussing their designs prior to testing them. On another occasion, one student was building a large turbine with two rows of blades, and another student remarked he was “trying to charge a battery”, which I believe was an indication he believed that the first student was making a turbine so large that it would produce a large amount of energy.

Students in week 1 had significant parent involvement during building and testing. Many students ended up working next to their parent, who was asking them questions about their design, test results, and thought processes while they worked. I did not observe parents telling their student what to do, but rather asking leading questions to help their student think it through, much as a teacher would. Week 2 did not see parents working alongside their students, rather parents in week 2 sat off to the side of the room while the students worked. I believe students in week 1 reached a better understanding of their designs and test results during the testing phase. However the presentations and "best" turbine discussions in week 2 displayed a similar understanding as week 1, so it is possible the increase in one-on-one interaction due to parent involvement had little effect overall. More experimentation would be desirable to understand this result.

5.5 Transfer

Transfer of concepts from one context to another was difficult to observe due to limited time available to work with particular students. However, many students were observed to connect their wind turbines to fans and aircraft propellers. During group 1's "best" turbine design discussion, one student suggested making a turbine with 5 blades, because most fans have 5 blades and it should be modeled after a fan. Another student in the group suggested using popsicle sticks because they are flat like fan blades. Another student stated he thought the lesson was fun because "we got to make little things that look like… the front of an airplane."

One particularly interesting example of transfer occurred during group 1's building time. I suggested to a student that he should use less tape, that often kids use much more tape than they need. He responded with a flash of recognition and said "What is it? Thrust, lift, drag, weight. Too much weight will cause it to like, sink down, then it won't move." He connected his turbine to his previous knowledge of the four forces of flight. His application of his previous knowledge was not perfect (there would additionally be a drag concern with too much tape) but he had made a connection to a different, previously encountered context to inform his turbine design.

Transfer could be more appropriately assessed with summative assessment at the conclusion of the lesson, as discussed in Chapter 3 of this report. Due to the nature of the testing environment, and individual summative assessment was unable to be performed.

Chapter 6 - Conclusion

Overall, students were successful at performing the design challenge, discovering concepts associated with wind turbine function, and utilizing professional engineering practice. The lesson was essentially age-appropriate, and students were able to navigate the requirements of the design challenge, without sacrificing the essential elements of an effective design challenge.

Most of the requirements for an effective design challenge outline in Chapter 3 were successfully incorporated into the lesson as enacted in the scout camp lesson. The lesson was weak on collaboration, because the students did not work together to solve the problem until the end. The lesson lacked an anchor problem the students were trying to solve. And the lesson lacked a summative assessment element, due to the informal classroom in which the lesson was administered. All other requirements were satisfactorily implemented.

Based on the data presented here, it appears that the design challenge was quite successful in teaching and eliciting engineering habits of mind in young students, and allowing students to explore cause and effect relationships. However student outcomes were less observable in the area of underlying principles involved in wind turbine operations. Students generally developed an understanding of force and its effects on the turbines, however generally did not equate turbine motion with electricity generation. However, the students were not working directly with electricity in their designs, but were working directly with forces and motion, so the fact that the forces outcome is stronger is expected. A summative assessment at the conclusion of the lesson would allow for better assessment of their facility with principles at work in their designs.

The self-selected nature of the students in the lesson cannot be ignored – the students are Cub Scouts and as such have a higher level of experience with building and higher parent involvement than might a typical sample of the population. It is encouraging that aspects such as self-direction were observed across different cultures in the different student groups. Additionally, the presence of parents on site during the lesson possibly made a significant impact. This effectively gave the student one-on-one time with an adult who helped them understand their design, test results, and where to go next. However, as stated in Chapter 4, the students held similar discussions of results with or without parent involvement during building, which is encouraging. This is something that would be difficult to replicate in a typical classroom.

Due to the informal setting of this study, further research is recommended into enacting the lesson in a traditional classroom environment. It is likely that a more formal environment will impact student performance of the design challenge, as will fewer adults available to provide feedback and leading questions. It is likely that preparing the students for how to conduct this type of lesson prior to conducting the lesson will make it more impactful.

Additionally, administering a summative assessment at the conclusion of the lesson will provide more insight into the efficacy of engineering design challenges at uncovering underlying principles with this age group.

Further research is recommended into students of different backgrounds conducting the challenge – students of different economic, cultural, and building backgrounds. It is likely that students will backgrounds other than those present at the Cub Scout camp will approach the challenge differently. Although this study was able to observe students of different cultural backgrounds, further investigation into those differences is recommended.

Based on the data presented here, I recommend the following alterations to the lesson plan were it, or any other engineering design challenge to be performed in a traditional elementary classroom.

1. Provide instruction for students prior to performing an engineering design challenge on how to perform effective record-keeping, what to look for and write down; effective brainstorming and developing a plan prior to building; interpreting results and making decisions based on test results.
2. Limit the choices for building, at least initially. Students in this study often lacked inspiration or did not see how to take the raw materials and turn them in to an idea initially. In the case of the wind turbine lesson, teachers could provide a selection of pre-cut blades of different materials, and allow students to select from the options what materials and how many blades they would like to try first. As students gain familiarity with the challenge, the options could gradually be expanded to allow them to create whatever they designed themselves. This would provide a structure to the initial building that may decrease feelings of not knowing where to start, or feeling overwhelmed by so many options.
3. Have a more structured building and testing time. Allow every pair to build their first design, and then everyone tests at the same time. This reduces the chaotic environment (especially if there is only one teacher) and allows everyone to see everyone else's test

results, and reminds everyone to record their design and test result in a more formal way. Then allow them to build their next idea and test together, and so on. This would, however, require students to work at the same pace, and some quicker students would be forced to wait while others finished before they could test. It would be up to the teacher to determine which format would best fit their classroom.

4. Use the story paper to record design and test results, then tack the story paper on to the storyboards. You could keep the storyboards tacked to the wall near where a team is working, to which they add story paper as they go along. This allows everyone to see results, and keeps their work area clear and organized.
5. At the start of each building session, review with students what they are trying accomplish with their designs, and what they discovered last time. During the review you could add discussion of underlying principles, and elaboration on those principles, as they are discovered and reported by students. This will allow students to then turn around and apply those principles to their next designs.
6. Conduct a summative assessment at the end which allows you to assess both content knowledge and engineering habits of mind.

In summary, this study has shown that effective engineering design challenges can be age appropriate for elementary students even as young as the 1st grade. The conduct of engineering challenges requires training for students and teachers alike in their administration in a classroom, but there are no barriers which cannot be overcome. EDC's are not the most efficient method for delivering science content, but I believe I have argued successfully that they may have a place in an elementary science curriculum that is interested in developing student's mind beyond solely knowledge of content.

Chapter 7 - Application to Practice

The UTeach MASEE program has had a dramatic impact on my teaching in general, and in teaching engineering in particular. I teach three different classes, and the MASEE program has impacted each one in the area of engineering.

My 6^{th} grade science class is primarily a class in physics, and traditionally has contained two large engineering projects to support physics concepts – one in the fall, where students design a device to reliably and accurately keep track of small amounts of time, and one in the spring where students build their own musical instruments out of recycled materials. These projects both existed prior to my joining the magnet program, so I was not involved in their development. However my experiences in the MASEE program allowed me to improve the projects to more accurately reflect engineering practice. I redesigned the record-keeping of the students during the project, to be more meaningful and more purposeful. I revised what the students were required to do in the reflection portion of the project, to emphasize the design process they went through and the physics content, and de-emphasize less important reflection pieces.

Additionally, my attitude towards the projects shifted – I became less concerned about them making a successful product and more concerned on teaching them to value the process and see the “failed” attempts as valuable steps along the way to the final product. This attitude I feel I gained from the education classes, and studies on productive failure and the importance of reflection.

One striking observation I made in my students’ engineering practices came when I overheard two students working together on a propeller they were designing. As they worked on the propeller, one of the students said to the other “Dude, I don’t think this is going to work.” The other responded “That’s ok, it’s a learning process.” I was overjoyed to hear this. Teaching students to view failure of any kind, in this case a failed design idea, as productive toward success has been one of the major take-ways for me from this program, and one of the fruits I have seen in some of my students.

Through my studies in education in MASEE, I have developed an appreciation of open-ended questioning, in allowing room for multiple ideas and solutions, outside of the engineering context, provided those ideas have a reasonable basis. For example, I modified a previous test question about simple machines in which students must design 3 different simple machines that will provide the needed mechanical advantage to do a specific job. The students must draw the machine and include measurements. This question is open-ended in that there are many acceptable designs, so long as they provide the needed mechanical advantage. Then I asked students to tell me which of their three machines the kid in the problem should use, and explain why. There is no correct answer to this question, they could give any number of reasons for favoring one machine over the others, so long as they had a justification for their choice. This question design came directly from my experiences in MASEE classes.

Through my experience in MASEE program, I developed an intuitive understanding for engineering process, and how that process can be effectively translated to a classroom lesson. This report, as well as previous engineering classes, firmly established for me what is engineering, and what it looks like in a classroom. I was motivated to pursue this particular project out of a desire to communicate what an engineering project is to educators with no experience in engineering at all, who may not feel comfortable incorporating it into their classrooms. This past school year I effectively mentored a fellow teacher who was creating a new engineering elective in the elements of an effective design challenge, assisting her in taking ideas for classroom projects and translating them into effective lessons.

Another thing the MASEE program taught me is the importance of the iterative nature of engineering design. One class I taught, Introduction to Flight, had always consisted of multiple building projects in which students build things that fly. Each project involved building and flying only once, and many involved building kits, with no room for variety of solutions or revision of designs after testing. It had always been an enduring struggle for me to connect the flying objects to the underlying scientific principles involved. As a direct result of my experiences in the MASEE program, I overhauled the class to be entirely engineering design challenges, with no set solution, and each challenge focused on an aspect of flight, such as lift or thrust. As a result, I have witnessed students gain a more intuitive understanding of the principles of lift, for example, rather than trying to remember Bernoulli's principle and how it relates to wings. I have incorporated many other aspects of engineering practice – such as purposeful record-keeping, test against nature rather than other students – but I feel the iterative aspect has had the most impact on the students' experience in this class, and is supported by the research on this project.

Finally, the most important thing I gained from this experience is professional expertise. I pursued education as a second career, and so got my teaching certification through an alternative certification path. While I do feel I was acceptably prepared by the certification course to enter a classroom on the first day, I don't believe that experience truly prepared me to be a professional educator. What I learned in UTeach MASEE program was current research-based educational theories. Things like Piaget and Dewey were brand new to me. I immediately synthesized and applied everything I learned, and continued to grow and expand my application of educational theory throughout the 3 school years I was part of UTeach MASEE. Doing research in the field of education pushed me beyond learning theory into developing and testing hypotheses in the science of education. Because of that, I now no longer feel like a teacher, but a professional educator with expertise in my field. And I have noticed a difference in how my students learn in my classroom because of it. I don't know if it will translate to higher test scores, but I know my students are having a more enriching classroom experience than before I began MASEE.

Appendix 1 – Wind Turbine Design Challenge Lesson Plan

<table>
<tr><td colspan="2">Engineering in the Elementary classroom:
Wind Turbine Design Challenge</td><td></td></tr>
<tr><td>Essential Question(s)
How can we make a wind turbine that will make the most power?

Topical Question(s)
How can we measure how well our turbine is working?</td><td>Vocabulary
Voltage
Turbine
Blade
Hub
Power
Measurement
Design
Electricity
Voltmeter</td><td>Objectives
Students will be able to:
- Measure the voltage output of their turbine design
- Use test results to inform design decisions
- Communicate their results to the class
- Describe the factors that influence wind turbine effectiveness
- Describe the roll of wind turbines in energy production
- Describe how energy used in homes comes from a source, such as wind</td></tr>
<tr><td colspan="3">Standards (TEKS)
112.12 Science, Grade 1:
- b(2)(a): Ask questions about organisms, objects, and events in the natural world
- b(2)(c): collect data and make observations using simple equipment such as… non-standard measurement tools
- b(2)(d): record and organize data using pictures, numbers and words
- b(2)(e): communicate observations and provide reasons for explanations using student-generated data from simple descriptive investigations
- b(3)(a): identify and explain a problem… and propose a solution in his/her own words
- b(3)(b): make predictions based on observable patterns
- b(6)(a): identify and discuss how different forms of energy such as light, heat and sound are important to everyday life
- b(8)(d): demonstrate that air is all around us and observe that wind is moving air</td></tr>
</table>

Materials:

Test stand: (Number per test stand)	Student materials:
(1) Basic tinker toy set. Retails for about $20 on Amazon (1) Hobby motor (5) Zip ties (1) Foam poster board (one board will serve many test stands) Electrical tape Stranded electrical wire (2) Alligator clips (1) Multimeter Masking tape (1) Light bulb or LED (1) Industrial fan Knife or box cutter	Paper Cardstock File folder Thin plastic that is easy to cut Styrofoam cups Plastic cups Transparency film Tapered cork stoppers, multiple sizes Toothpicks, the kind pointy on only one end Scissors Safety glasses or goggles

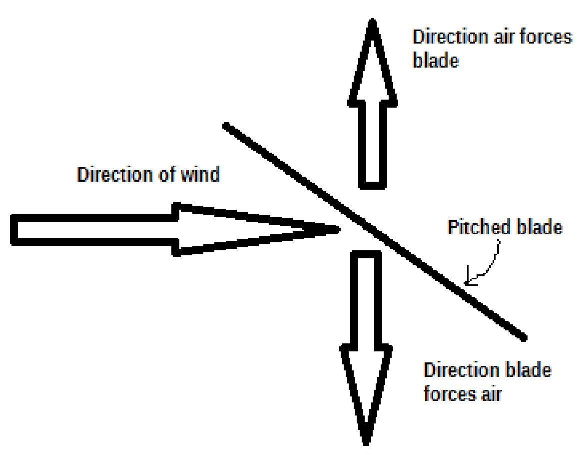
Teacher prep:

- Assemble the test stand and generator according to the instructions contained in Appendix B.
- Gather the student materials listed above. Be sure to gather multiples of everything to allow for many iterations of design and testing. You are not limited to the prescribed materials; allow students to use anything they may find, or you may find, for their turbine blades.
- Construct a poorly functioning prototype turbine.
- Prepare storyboards for each student team. One storyboard per pair of students.

Background information for teachers:

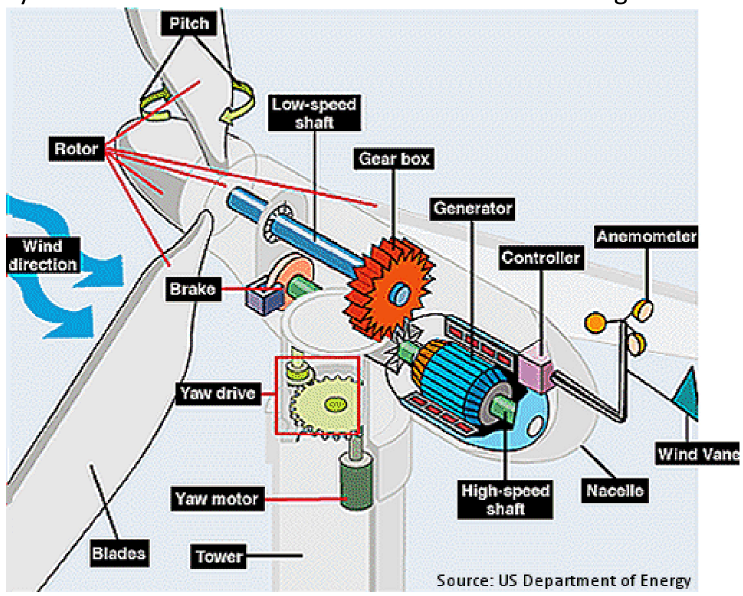
Wind turbines use kinetic energy of the wind, which causes the turbine blades to spin, which spins a generator inside the hub, to create electricity.

Most wind turbines used in commercial power generation have three long skinny blades. The blades turn due to Newton's 3rd law of motion which describes forces acting in pairs. The blade is pitched (angled) so that when the wind hits the blade, the blade deflects (pushes) the wind in one direction, and therefore puts a force on the blade in the opposite direction.



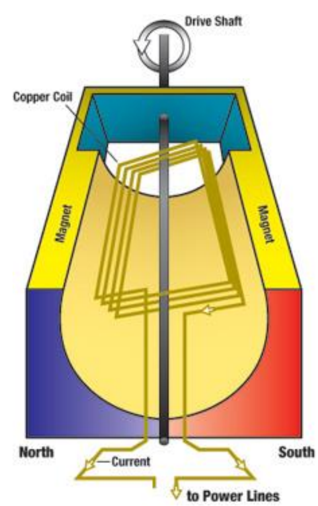
Without the pitch angle, the blade will not spin. The optimum pitch angle will be the one that produces the maximum force on the blade in the direction of rotation. The precise optimum angle will vary depending on blade design.

The more rigid the blade material, the more of the kinetic energy of the wind is translated into rotational motion of the blade, and the less that is lost to blade movement other than rotation. Blades on commercial wind turbines have a slightly curved surface, however for this scaled-down model in this lesson you will find a flat surface will work best. Encourage students to try different things, such as plastic cups, but they should find flat blades work best.



The spinning blade then translates motion to a gear box, which converts the slow rotation speed of the turbine blades into fast rotation speed at the generator.

Generators use rotational kinetic energy to create electricity. Coils of wire moving through a magnetic field create electricity flow in those wires. Wind turbine generators get that movement from the turning turbine blades. Steam powered turbine generators use steam to turn a turbine which turns the generator. Diesel generators use the exploding diesel fuel to push on pistons which turn a shaft connected to a generator. Water turbines (dams) use falling water to turn a turbine connected to a generator. A nuclear power plant is simply a steam turbine using nuclear fission as the heat source to create steam. Most energy generation methods are just different ways to get that generator to turn to create electricity. The image to the right shows a simplified version of a generator.



When the flow of energy is reversed, and electricity is put in to a generator, it becomes a motor. The electric fields cause the shaft of the generator to turn around, therefore becoming a motor. This is why, for this lesson, we are able to purchase a hobby motor and use it as a generator.

Lesson Procedure:

Discussion: Context is crucial for design challenges, to connect the activities inside the classroom to the world outside the classroom. This challenge can be used as part of many units in elementary science curriculum. It could be part of an energy unit, connecting to energy resources and renewable vs. non-renewable energy resources. It could be part of a resources conservation unit, connecting to green energy and energy conservation. It could relate to electricity and magnetism, and motors/generators.
Whatever the context, it is essential the students see the challenge as connecting to life outside the classroom.

This lesson plan is not divided into days, because each class will work at a different pace. Given an hour-long class period, this is an approximate breakdown of timeline for the lesson:

Day 1	Introduction Begin brainstorm and building process
Day 2 - 3	Building and testing
Day 4 - 5	Share results Create a class "best" turbine Individual Assessment

Allow several days for building and testing – more is better. Use your judgment to determine when the "creative energy" or enthusiasm for the design process is beginning to wane.

Actions

Take out you cell phone or other battery powered device.

Ask:

- My cell phone battery is dead. What should I do?
- Why do you plug it in? What comes out of the socket?
- Where did that electricity come from?

Say:

- Energy has to come from somewhere, it can't just magically appear. Another word for when energy is being used, it's called **power**. Let's look at energy sources that power your house.

Watch the Energy video on BrainPop Jr.
(http://www.brainpopjr.com/science/energy/energysources/)

Ask:

- What are some of the sources of energy Annie talked about?
- What is the difference between renewable and non-renewable source of energy?
- Which do you think is a better choice to power your house, renewable or non-renewable sources? Why?

Visit the Austin Energy At-A-Glance page to see what resources the City of Austin buys to power our houses: http://austinenergy.com/wps/portal/ae/about/at-a-glance/austin-energy-at-a-glance/
(Note: Visit the same page for your city if you do not live in Austin).
(Note: At the time of the writing of this lesson plan, the most amount of energy purchased by City of Austin was wind. This is significant to point out as it connects to this lesson)

Optional Extension:

1. Have students interview their family, friends, neighbors about energy resources, their opinion of wind as an alternative energy source

Ask:

- Has anyone ever seen a wind turbine before? Where?
- What does it do? (Convert energy in the wind's movement to electricity)

Look at pictures online of wind turbines in operations and discuss the features you notice. See Appendix A of this lesson plan for photos. You can also search online.

Ask:

- What do these turbines have in common?
- What do you see that is different between them?

Remind students that all of these turbines are designed to do the same thing (convert energy in the wind to electricity) but they all look different. So there isn't any one design that works the best.

Introduce the problem. Write it on the board.

Problem: How can we create a wind turbine that will produce the most amount of power?

(Note: It is best to introduce the problem first thing, before giving information and parameters that will define the limits of the problem. Introduce the problem before telling students necessary information such as voltage or how we will determine a successful design. This requires the students to consider how to address the problem, discover the need for this information, and ask the teacher for it. This creates authenticity for the information they discover they need.)

Now demonstrate your prototype. Allow students a moment to observe and discuss with each other the testing apparatus. Turn on the fan and allow them to see the wind from the fan causing the turbine to turn.

Connect your prototype the leads from the generator to the multimeter.

Say:

- Electricity is measured in **voltage**: more voltage, means more power, means our turbine is creating more energy and working better.
- This is called a **voltmeter**, it measures voltage. A bigger number means there is more voltage. See the numbers on the voltmeter?
- For this project, your challenge is to design (make, create) a turbine that will make the voltage numbers even bigger than this! As big as you can possibly make them! That means your wind turbine is working even better than mine!
- I know you don't know how to do that yet. That's why you're going to think like an Engineer! Try different things to see what happens to the voltage numbers. Some things will work well, some things will not. That's ok, that simply tells you what makes a turbine better and what doesn't.

(Note: This last statement is important. Young students tend to get frustrated if they don't know the answer right away, or don't know how to do something, or make something that doesn't work the first time. That is what is good about an engineering challenge. It's helpful to connect this project to professional engineering practice, and to reinforce to kids that adults don't get it right on the first try, and that a failed design helps you learn what not to do next time. You can maybe link it to a guessing game where each test gives you a clue.)

Say:

- This part of the turbine is called the **blade**
- This part is called the **hub**

Ask:

- What are some things you could change about my turbine to see if it makes the turbine work better?

Write on the board what they list as possible things to change. Refer back to the pictures and prototype to spur ideas.

For example:

Number of blades
Angle of blades
Material of blades
Size of hub
Placement of blades
Blade size and shape

Students will work in pairs. Either allow them to choose a partner, or assign them a partner.

Show students their materials options for the project. Remind students that they can use whatever they want, they are not limited to just these materials.

Allow students to examine, discuss and even handle the prototype. Throughout the lesson, keep the prototype near at hand, so students can return to examine it if they want to.

(Note: This is especially important for younger students who may lack familiarity with building things and who have difficulty with mental manipulation and may require more concrete examples.)

Release students to work with their partners to brainstorm ideas. Do not let them grab materials yet, however do allow them to handle materials and prototype as they brainstorm.

After about 10 minutes for brainstorm, give each pair a storyboard for documenting (see Appendix B). Explain to students how they will document their results each time they do a test.

Release the students to tackle the challenge. Monitor students for documenting, and help with building. ***Students should wear safety goggles while testing.***

> ***Important: Be very careful to refrain from suggesting solutions or judging whether an idea will succeed or fail before it is tested. Be very careful not to give any hint at all! The students ***must*** be given room for their ideas to fail.
> Be careful to cultivate an atmosphere that encourages trying ideas, and does not condemn failed ideas. Encourage the students to see a failed idea as opportunity for improvement rather than a failure. Encourage the students to examine why their idea may not have worked, and what they could change to see if it will improve performance. Give no hint of judgment.***

Allow students to work at their own pace, and test as often as they like.
(Note: Once you have helped students with their first or second tests, they should get the hang of how to perform tests and will likely be able to test on their own, freeing you up to monitor groups and record-keeping. Some teams might test often, while some who work more slowly or deliberately test only two or three times. This is ok and should be supported. Allow a long interval for testing, several class days, so that student teams will be able to perform multiple iterations of testing. Each team should perform at least 2 or 3 design and test iterations.

Remind students to document each iteration on the story board.

Notes for the teacher on building and testing:
If you have the materials, it would be beneficial to construct two or three test stands, so that more teams can test at any one time, and therefore allow for more iterations.)

Younger students may need help determining what to write down, because the voltmeter reading will bounce up and down. It is probably best for younger students to record the highest number they see, rather than trying to find an average number. This is also good exposure for students to recognize that in the real world numbers aren't always as precise or even as we would like, they vary and change.

Additionally, the most likely readings you will see are numbers that are less than one volt, so it will display decimals. Younger students may not have been exposed to decimals. Remind students that larger numbers are better, and 0.4 is bigger than 0.2 volts, just like 4 is bigger than 2.

Depending on the direction of rotation, the voltmeter may display a negative number. This simply indicates the direction of rotation of the generator, and can be safely ignored by the students.

After the design and testing phase is over

Gather the class together to share their results.

Say:

- Now each team will share their storyboard with the class, and tell us the story of your team's wind turbine.
- Be sure to tell us what you did, why you wanted to do it that way, and what the results were for each turbine you tested.

Allow each team to show their story board and tell the story of their idea as it progressed from beginning to end. Allow other students to ask constructive questions about a team's experience.

After all teams have shared:

Ask:

- What do you think are the most important things that made the turbines work well?

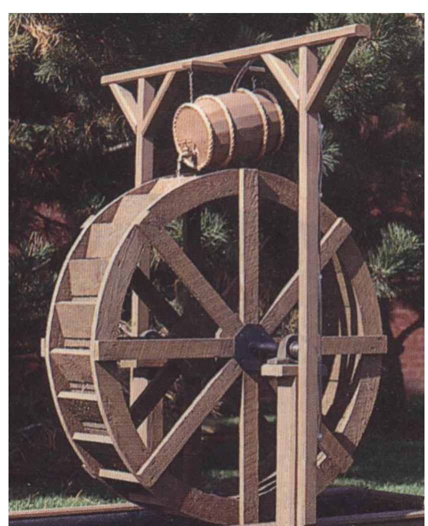
Create a list on the board of design features that worked best, based on all the results the class shared.

Say:

- So what do you think the best possible wind turbine ever would look like?

Write their answers on the board, or allow them to draw on the board, discuss together, even argue about what it would need to look like. If there is an argument, encourage students to articulate their thinking behind their idea, say why they have that opinion.

Optional extension: Create the class "best" turbine you just designed. Test it and see how it does.



Individual Assessment:

Have each individual student write a paragraph about what they learned about what makes up the most successful wind turbine. This will allow you to assess each student's individual learning, while the story board can serve as assessment for the team and how they approached the process.

Guiding questions for student paragraphs:

1. What does a wind turbine do?
2. What would a good wind turbine look like?

Extension: connect the principles at work in a wind turbine to a different context.

a. Remind students what a wind turbine does (converts energy in the wind to make the turbine turn a generator, to make electricity). Show students pictures of other electricity-generation methods, such as a water turbine (dam) or steam turbine. Ask students to write a paragraph about what the source of energy is in each generation method, and how it relates to how wind turbines work.
b. Remind students of the features that made the best blades (rigid, angled). Examine the design of airplane propellers. Have students write a paragraph about how airplane propeller design relates to wind turbine design.
c. Make a gravity-powered coke can Hero engine. Write a paragraph about how the falling water making the can spin relates to the wind making the turbine spin.

Lesson Plan Appendix A – Wind Turbine Images

Images obtained from: http://www.small-windturbine.com/Vertical-Wind-Turbine-Power-Generators.htm
http://earthtechling.com/2010/09/home-topper-wind-turbine-beefs-up-output/
http://www.treehugger.com/renewable-energy/backyard-wind-turbine-by-wind-simplicity-mirrors-art-and-nature.html
http://en.wikipedia.org/wiki/Post_mill

Lesson Plan Appendix B: Preparing the materials

Materials discussion:

Multimeter:

Either digital or analog will work. This one worked well, about $20 at RadioShack: http://www.radioshack.com/product/index.jsp?productId=4214667 When it is set to 2V setting, it displays three decimal points, so allows for a good amount of differentiation between results. If the generator turns the wrong direction, the multimeter displays a negative, to indicate current is flowing in the wrong direction, which is a nice and dramatic result students can see.

Motor:

When electricity is put in to a motor, the shaft turns. When the shaft is turned, the motor creates electricity which flows out of the leads – it becomes a generator. Thus, these small cheap motors from RadioShack make good generators. I got good results with this motor:
http://www.radioshack.com/product/index.jsp?productId=2102827
It's rated for high RPMs output, but when I turned the shaft with my hands I got up to 0.4V, which was a significant enough readout on the multimeter. Smaller voltage motors will work better because they spin at lower RPMs, and so need lower RPMs to generate voltage. I also tried a 1.5-3VDC motor, but got better results from the higher voltage motor.
This site has an excellent discussion of motors for use in homemade wind turbines, with many suggestions for motors you could buy that work well:
http://www.otherpower.com/toymill.html

Stranded electrical wire:

Look for stranded rather than solid, because it makes a better electrical connection when used in a context like this. RadioShack or Fry's electronics will carry both.

Corks, multiple sizes:

Tapered cork stoppers are used as the hub of the wind turbine. Having multiple sizes to choose from gives another variable for design variation. Larger corks will be easier to stick onto the hub, but have more mass than smaller corks. Wine corks could be used, but you might want to split them in half as they are rather long.
When shopping online search for "cork stoppers" rather than wine corks.
Here are some examples of the type of corks

that work well for this:
http://www.amazon.com/ASTRODEALS-Cork-Stopper/dp/B003ZFLLO6
http://www.walmart.com/c/ep/cork-stoppers
http://www.ebay.com/itm/Tapered-Cork-Stopper-Size-4-SET-3-12-36-bottle-vial-jar-plug-5-8-x-15-32-NEW-/190789754098

Toothpicks:
Toothpicks are used to attach wind turbine blades to the cork hub. I like using the toothpicks with one flat end, so there is only one sharp end for sticking into the cork. Probably not a good idea to use the kind with the colored plastic on the ends.

Industrial fan:
For this lesson I used a small portable industrial floor fan rather than a box fan. I was unable to get the turbine to turn with a standard box fan, and needed more wind output than the box fan could provide.

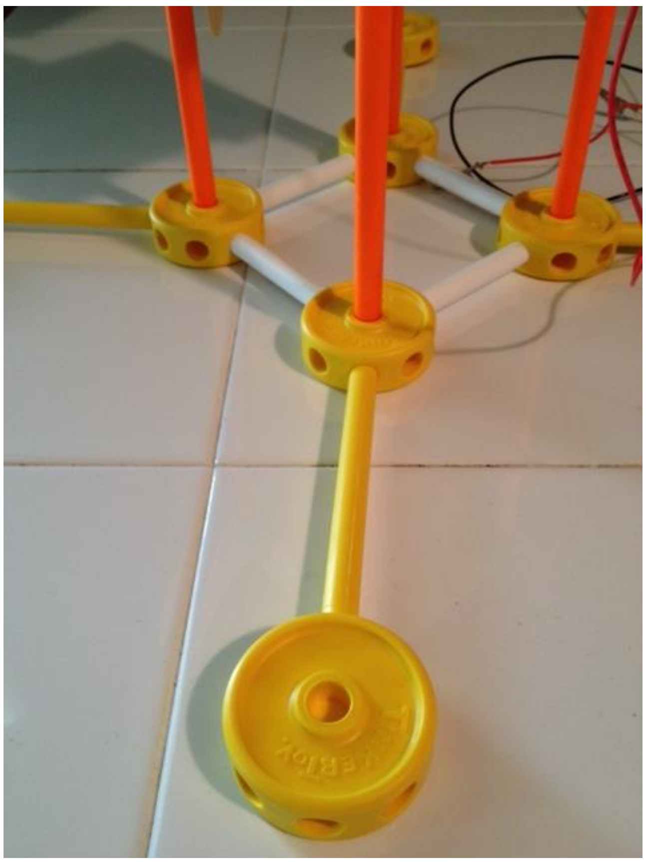
Assemble the generator:
Take two lengths of stranded electrical wire (they don't have to be different colors, but it is helpful if they are). Strip both ends of both wires (if you don't have an electrical wire stripper, you can use scissors to carefully cut through the insulation. Hold the wire near the fulcrum of the scissors and clamp down gently – be careful not to cut through the wire, only the insulation. Rotate the wire within the scissors to cut through the insulation all the way around. When you see the wire shining through all the way around, pull the scissors up to pull the insulation off the wires.) Strip approximately ½" of insulation from each end.

Slide one end of each wire into each of the leads on the motor. Wrap the ends of the wire around the motor leads. Place the other end of each wire through the hole in an alligator clip. Wrap the rest of the wire around the alligator clip and crimp the end of the alligator clip with a pair of needle-nosed pliers. Clip the alligator clips to the ends of the multimeter. Turn the multimeter to the 2V setting. Spin the motor shaft by hand. You should see some voltage created on the multimeter!

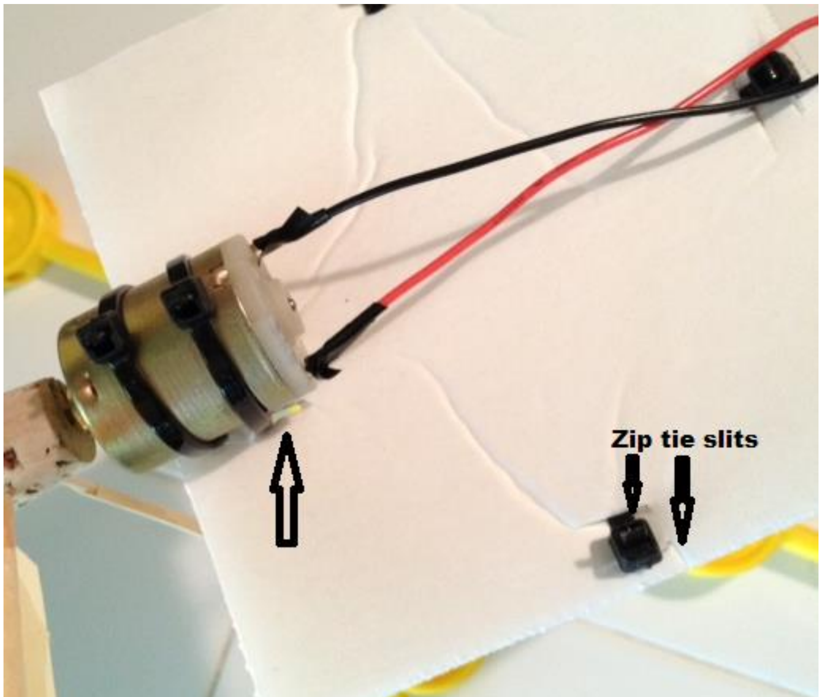
Assemble the test stand:
The test stand and motor assembly is made out of a Tinker Toy set, with zip ties and foam board.

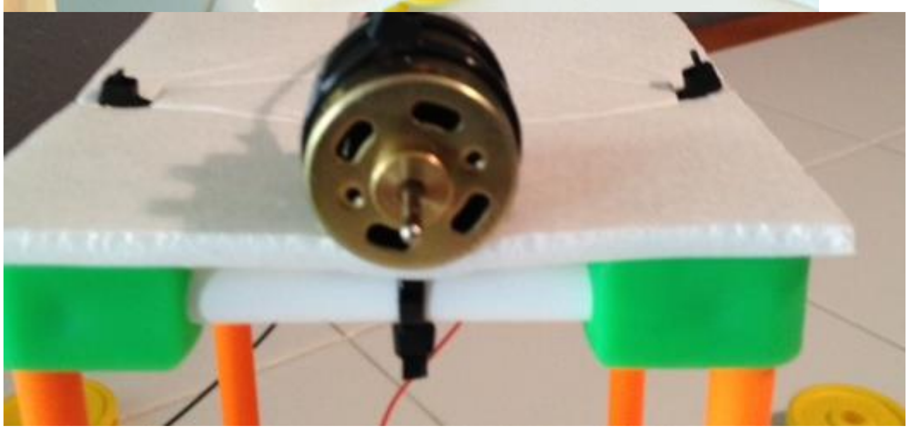
1. From the Tinker Toy set, take 4 green corner pieces and 4 white sticks and assemble them into a square.
2. At the bottom of each green corner piece, place a large orange stick into the hole.
3. Place one yellow circle piece on the bottom of each orange stick.
4. Connect the yellow circle pieces with 4 white sticks to complete the square at the bottom.
5. Attach one yellow stick to the hole directly opposite the square stand of each yellow circle piece, so that the bottom of the stand has 4 sticks yellow sticks sticking out of each side to provide lateral support.
6. Attach another yellow circle piece to the yellow sticks to make feet for supporting the stand.
7. Place weights of each foot or tape the feet to a table to prevent the stand from moving when the fan is turned on.
8. Cut a square from foam board that is just a bit bigger on each side than the top of the test stand.
9. On 3 sides, use a knife to cut two small slits in the foam board, one on each side of the white stick. Place a zip tie through the outside slit, under the white stick, then up through the inside slit, to hold the foam board to the stand.
10. Perform the actions in the “assemble the generator” instructions below.

11. On the fourth side, place the generator in the center of the edge with the motor shaft and a bit of the motor casing hanging out over the edge. On either side of the motor, cut two sets of slits in the foam board, one near the front and one near the rear of the motor. Slide a zip tie down through one slit and up through the other. Repeat with the other set of slits. Leave the zip ties loose for now.
12. Slide another zip tie through the underside of the two motor zip ties. Fasten it below the white stick and tighten it.
13. Tighten the two motor zip ties across the top to hold the motor in place. Make sure the zip tie is a tight as possible. Trim the ends of the zip ties.

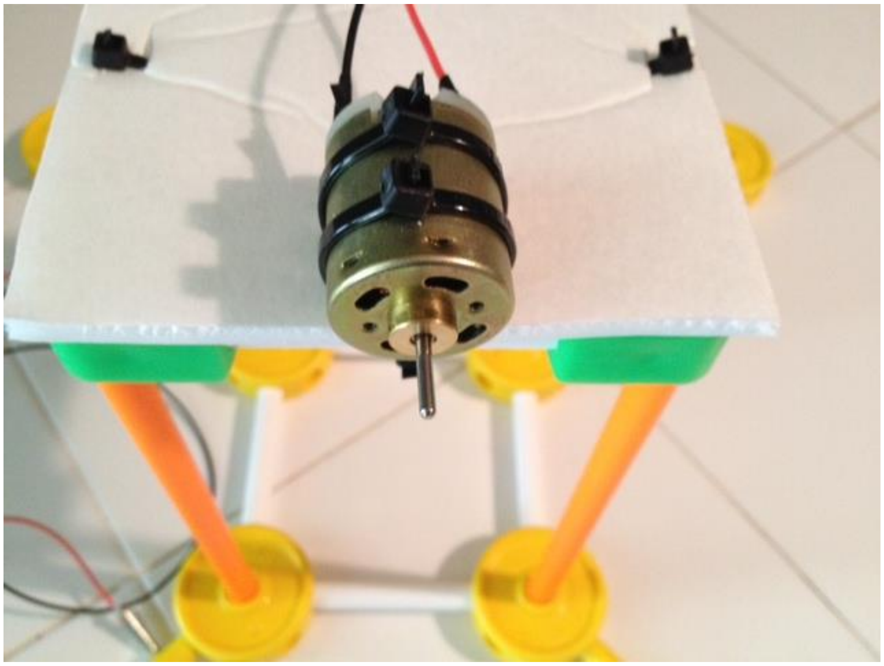


Test stand feet

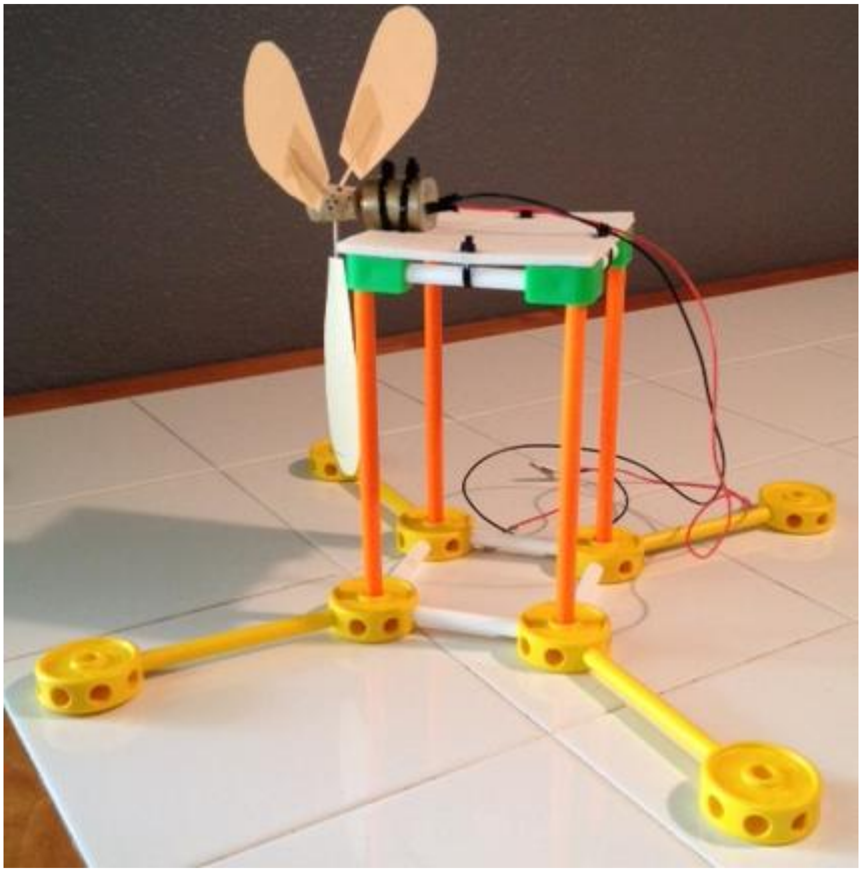




Attaching the foam board and motor to the test stand


Motor attached to test stand


Assembled test stand with prototype turbine



Completed test stand and prototype.

Assemble the prototype:

Before the lesson, you will want to create a poorly-functioning prototype to get the students' minds' thinking about the problem, and challenge them to make one that works better.

Choose a medium sized cork stopper. Poke the smaller end of the stopper onto the motor shaft. Try to poke the shaft in as straight as possible, to minimize imbalance. Cut out some blade shapes from a stiff material such as file folder. Use masking tape to attach each blade to toothpick. Stick the toothpick into the cork hub. Attach to motor shaft. Now you have a wind turbine.

You want your prototype to function, but poorly, so students can be challenged to make one that works better. But it can't be so poor that it doesn't spin, or you will get no result. Ways to make your prototype poorly-functional:

- Have only two blades
- The blades are small
- The blades are not symmetrical
- The material isn't very stiff or too floppy

- The blades are too thin or too fat
- No pitch to the blades (blade angle from the plane of rotation)

A prototype, close-up of blade attached to toothpick

Lesson Plan Appendix C: Documenting design process and results.

Students should be reminded continuously throughout the building and testing process to document their designs and test results. Students often fail to see the inherent value in documenting everything that will be essential information at the end when discussing results and creating the class "best" filter.

There are several options for documenting. I have required students to keep an engineer's notebook, which is periodically assessed, with middle school students. In fact with high school, and older or more advanced middle school students, this is the best option for documenting because it mimics the practice of professional engineers.

For younger students, an engineer's notebook is most likely not practical. For elementary students I advocate for the use of story boards. Story boards are posters or papers which provide a structured place for students to document what they are doing as they progress through linearly, to enable them to format their thoughts and their work in a logical, chronological way. For younger students, providing them with the cells of the story board, for them to fill in as they go along, scaffolds their thinking, and enables them to keep accurate, logical records of their work. Each student team should create one story board for the whole team.

Figure 1 shows an example story board created by a teacher and provided to older elementary students. Students draw a picture of their first idea in the first cell top left, including materials labeled on the drawing. When they perform a test, they should write the test results in the cell next to, below or above their drawing. Students should be reminded to record quantitative (numbers) results, and qualitative (can't be measured by numbers) results in the cell. Students should also be encouraged to write down their thoughts or opinions about their design or their test as well. Encourage them to write down professional language, rather than everyday language (for example, "this one did not work very well" is better than "this one sucked.")

Figure 2 shows a story board with more scaffolding for younger students. It provides prompting for what they should be writing down with each test, and how to situate that information around the drawing of their design.
For even younger students, such as 1st grade, another option is to use the story board in conjunction with their lined "story" paper. Have each team use the story paper with the space for drawings on top. Students could draw their design in the space above, record their test results on the lines below, and then paste their paper directly on to the story board in the correct cell. In this way they are using materials they are familiar with, and the cells provide scaffolding for their thinking chronologically. This is illustrated in figure 3.

For younger students, it would be beneficial to create a prototype story board entry as well, to model how to document results in the story board or on the story paper. Conduct a model test using the prototype design. Document the prototype test results on a story paper, complete with drawing. Place the prototype test results in a conspicuous location so students can reference it during testing.

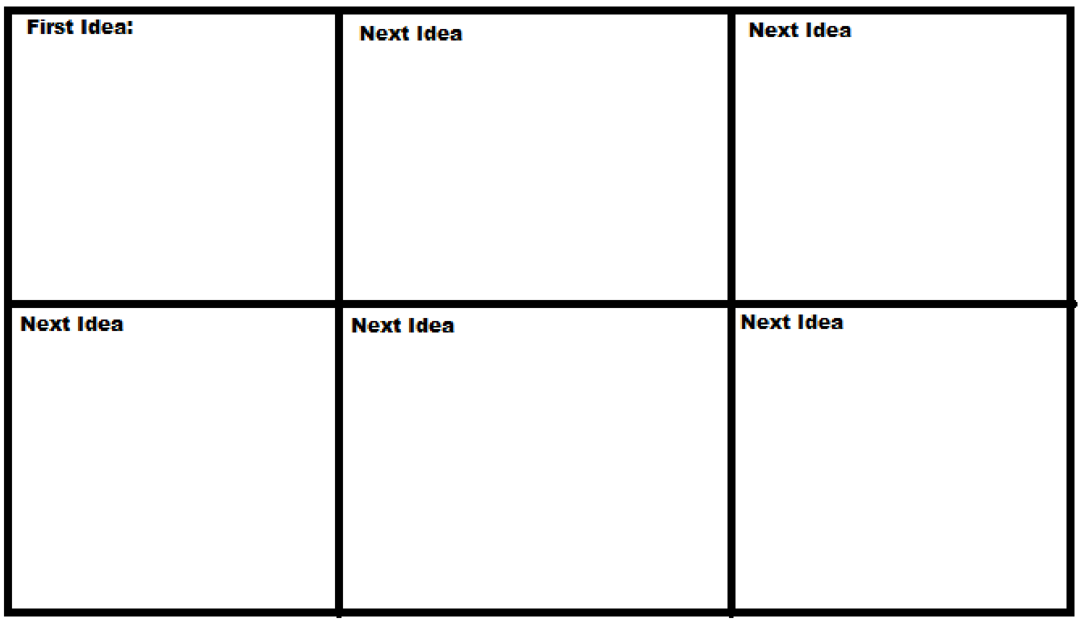


Figure 1

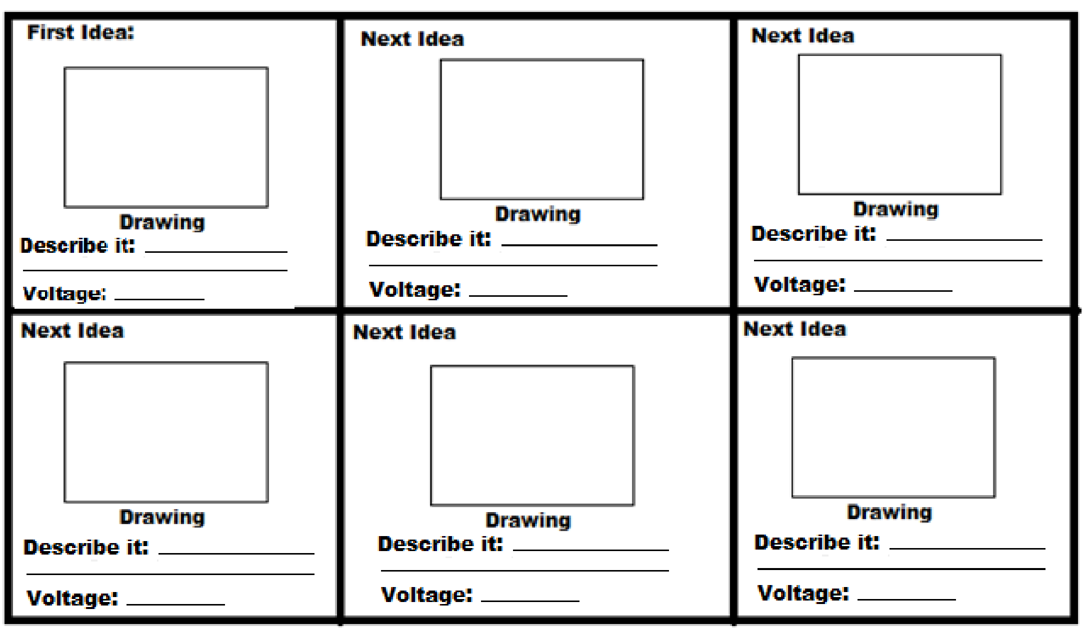


Figure 2

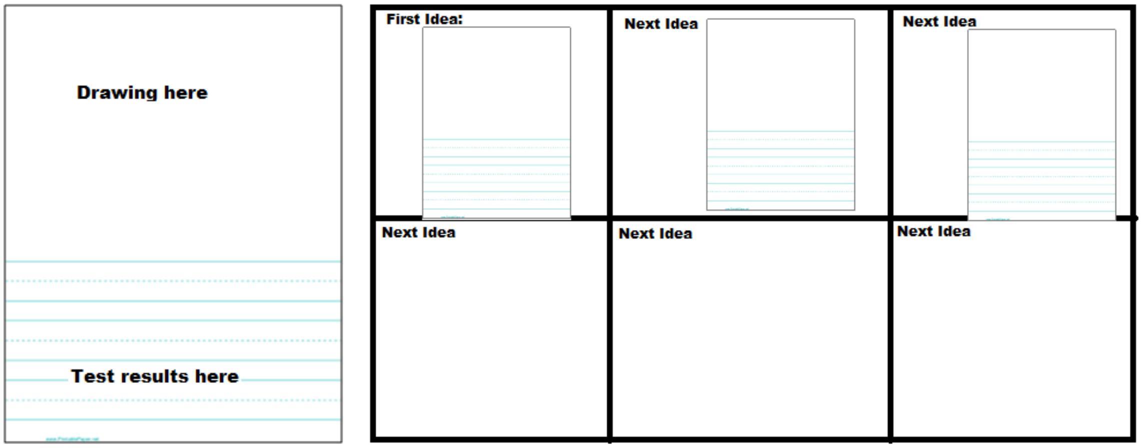

Drawing here
Test results here
First Idea:
Next Idea
Next Idea
Next Idea
Next Idea
Next Idea

Figure 3

Appendix 2 – Research Study Materials

Letter to parents explaining study

Dear parents,

My name is Logan Pearce, and I am a graduate student at the University of Texas in engineering education. I am studying the impact performing engineering challenges in classrooms has on students' intellectual development. Much research has been done on engineering in the classroom in middle and high school levels, but relatively no research has been done on engineering for elementary students. I am curious – are the methods which have been demonstrated to be successful at higher grades also successful for elementary students? Can elementary students successfully perform engineering tasks? What are the impacts to student learning when elementary students engage in engineering?

Cub Scouts of America, Capital Area Chapter, is also interested in developing engineering habits into their young scouts. They have enthusiastically volunteered this camp as a site for my research into engineering education at elementary grades. I am writing you to ask your consent for your student to participate in my research.

Detailed information on my research and how it will impact your student is contained on the following consent form. In short, your student will participate in an engineering lesson as part of a normal class day. The only difference is that, for students who have elected to participate, I will observe your student interacting with the lesson and perhaps ask them a few questions about their experience. Students who participate may have their responses audio recorded as well. There is no penalty for your student should you decline to participate.

The goal of this research is to provide to the elementary education community as research-backed method for creating effective, engaging engineering lessons in their elementary classroom, which is derived from methods demonstrated effective at higher grade levels, adapted for younger grade students.

I hope you will consider allowing your student to be a part of my research. I am excited about the possibilities offered to younger students through engineering education.

If you have questions about my research or your students' participation, please don't hesitate to ask, as I will be on site during the camp session. You may also email me at: xxx.

Sincerely,
Logan Pearce

Cómo involucrar a estudiantes de primaria en un aprendizaje activo por medio de la ingeniería.

Estimados padres:

Mi nombre es Logan Pearce y soy un egresado de la Universidad de Texas con especialización en enseñanza de la ingeniería. Estoy estudiando el impacto que tiene en el desarrollo intelectual de los estudiantes el presentar desafíos de ingeniería en sus aulas. Se ha investigado mucho el efecto que tiene la ingeniería en los programas de estudio de la secundaria y el liceo, pero prácticamente no se ha investigado dicho efecto en estudiantes de primaria. Y quisiera saber ¿son los métodos que han probado ser exitosos en los niveles secundarios, igualmente exitosos en la primaria? ¿Pueden efectuar tareas de ingeniería con éxito los estudiantes primarios? ¿Cuál es el impacto en el proceso de aprendizaje cuando alumnos de primaria se involucran con la ingeniería?

La sección de la capital de los Cub Scouts también está interesada en crear hábitos de ingeniería en sus miembros. Me han ofrecido su campamento con entusiasmo como locación para mi investigación sobre enseñanza de ingeniería en grados de primaria. Esta carta tienen el propósito de pedir su consentimiento para que su hijo(a) participe en mi investigación. En el siguiente formulario de consentimiento encontrarán información más detallada sobre esta investigación y sobre cómo afectará a su estudiante. En pocas palabras, su hijo(a) participará en una lección de ingeniería como parte de una jornada normal de clase. La única diferencia es que aquellos estudiantes que sean elegidos serán observados mientras interactúan con la lección y quizá les haré un par de preguntas sobre su experiencia. Tal vez también se graben en audio las respuestas de aquellos que participen. No habrá penalización para aquellos estudiantes cuyos padres rechacen esta oferta.

El objetivo de esta investigación es dotar a la comunidad de docentes primarios de un método apoyado por la investigación, para crear lecciones efectivas y atractivas en sus clases, que se derivan de métodos que probaron ser efectivos en niveles superiores y que fueron adaptados a niveles más bajos.

Espero que considere el permitir que su estudiante sea parte de mi investigación. Estoy muy entusiasmado con las posibilidades que se pueden presentar para estudiantes más jóvenes por medio de la ingeniería.

Si tiene preguntas sobre mi investigación o sobre la participación de los estudiantes, por favor, no vacile en hacerlas, pues estaré presente durante las sesiones en el campamento. También puede enviar un correo electrónico a:

Cordialmente.

Parental Permission for Children Participation in Research

Title: Engaging Elementary Students in Active Learning Through Engineering

Introduction

The purpose of this form is to provide you (as the parent of a prospective research study participant) information that may affect your decision as to whether or not to let your child participate in this research study. The person performing the research will describe the study to you and answer all your questions. Read the information below and ask any questions you might have before deciding whether or not to give your permission for your child to take part. If you decide to let your child be involved in this study, this form will be used to record your permission. Your child will also be asked to sign an assent form to record their willingness to participate.

Purpose of the Study

If you agree, your child will be asked to participate in a research study about the effectiveness of engineering lessons at the elementary level. The purpose of this study is to apply current instruction and learning theory to the development of a lesson designed to teach a science concept, by using engineering techniques, and requiring students to design and build actual solutions to real world problems. Much research in this area has been focused on the high school level student. This research will examine the effectiveness of these instructional techniques at elementary grades. The result of this research is intended to assist educators in improving their practice and applying sound learning theory to their classrooms.

What is my child going to be asked to do?

Your child will participate in a lesson in their camp sessions, delivered by a Cub Scouts volunteer teacher. The lesson will be an engineering lesson in which students are given a problem for which they must build and test something to solve. All students will participate in the lesson as normal, even those who do not participate in this study. Your decision to allow your child to participate in the study will not affect their camp experience.

If you allow your child to participate in this study, they will be asked to:

- Talk about their thoughts as they perform the tasks required by the lesson. With your permission, your child's interactions with the lesson and problem solving approaches will be audio recorded.

- The researcher will observe the classroom, observe their interactions with the lesson and each other, and ask informal questions designed to get the students to talk about their thoughts as they participate in the lesson. The lesson will take 3 session days, approximately 45 minutes each.
- Your student may be asked to answer a few questions about their experiences during a short, one-on-one interview with the researcher. Questions will be targeted to their thoughts and feelings about what they experienced in the lesson, and what they liked/did not like about the experience. Formal interviews will take place outside of class time, such as during recess so that it does not impact their class day.

This study will take 3 session days and there will be a maximum total of 70 students in this study.

Your child may be audio recorded during the interview and observations for research purposes only. The recording will not be used by anyone other than the researcher, nor made public, and will be destroyed at the conclusion of the study.

There are no foreseeable risks to participating in this study.

What are the possible benefits of this study?

Your child will receive no direct benefit from participating in this study; however, the intent of this study is to assist educators in improving their professional practice, and to provide a resource for applying learning theory and best practices into their elementary classrooms, improving the quality of instruction in elementary classrooms.

Does my child have to participate?

No, your child's participation in this study is voluntary. Your child may decline to participate or to withdraw from participation at any time. Withdrawal or refusing to participate will not affect their relationship with The University of Texas at Austin (University) or Cub Scouts of America, Capital Area Chapter in any way. You can agree to allow your child to be in the study now and change your mind later without any penalty.

This research study will take place during regular session activities. If you do not want your child to participate, your child will not be observed or interviewed. Your child will interact with peers and the teacher as normal. There will be no penalty for not participating.

What if my child does not want to participate?

In addition to your permission, your child must agree to participate in the study. If you child does not want to participate they will not be included in the study and there will be no penalty. If your child initially agrees to be in the study they can change their mind later without any penalty.

Will there be any compensation?

Neither you nor your child will receive any type of payment participating in this study.

How will your child's privacy and confidentiality be protected if s/he participates in this research study?

Your child's privacy and the confidentiality of his/her data will be protected by anonymity. No child will be identified by name, or any other identifying characteristic such as gender or ethnicity, in the course of the study. Students will be referred to using a code. Any identifying characteristics, such as names and audio recordings, will be destroyed at the conclusion of the study.

If it becomes necessary for the Institutional Review Board to review the study records, information that can be linked to your child will be protected to the extent permitted by law. Your child's research records will not be released without your consent unless required by law or a court order. The data resulting from your child's participation may be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate it with your child, or with your child's participation in any study.

If you choose to participate in this study, your child may choose to be audio recorded. Any audio recordings will be stored securely and only the research team will have access to the recordings. Recordings will be kept for 4 months and then erased.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the researcher Logan Pearce in person on site, at xxx-xxx-xxxx or send an email to xxx for any questions or if you feel that you have been harmed. This study has been reviewed and approved by The University Institutional Review Board and the study number is **2014-03-0077**

Whom to contact with questions concerning your rights as a research participant?

For questions about your rights or any dissatisfaction with any part of this study, you can contact, anonymously if you wish, the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

Signature

You are making a decision about allowing your child to participate in this study. Your signature below indicates that you have read the information provided above and have decided to allow them to participate in the study. If you later decide that you wish to withdraw your permission for your child to participate in the study you may discontinue his or her participation at any time. You will be given a copy of this document.

______ My child MAY be audio recorded.

______ My child MAY NOT be audio recorded.

____

Printed Name of Child

_________________________________ _________________

Signature of Parent(s) or Legal Guardian Date

_________________________________ _________________

Signature of Investigator Date

Permiso de los padres para la participación de los hijos en una investigación:

Título: **Cómo involucrar a estudiantes de primaria en un aprendizaje activo por medio de la ingeniería.**

El propósito de este formulario es el de darle a usted (como padre de un potencial integrante del estudio de la investigación) la información que pueda incidir en su decisión sobre si debe permitir o no que su hijo(a) participe en este estudio. La persona que realiza la investigación le describirá el proceso y responderá a todas sus preguntas. Lea la información siguiente y haga todas las preguntas que desee antes de decidir si dará su permiso para que su hijo(a) tome parte en el estudio. Si decide dar su aprobación, este documento registrará su consentimiento. También se le pedirá a su hijo(a) que firme un formulario similar para expresar oficialmente su deseo de participar.

Propósito del estudio

Si accede, a su hijo(a) se le pedirá que participe en un estudio sobre la efectividad de lecciones de ingeniería en el nivel primario. El propósito de este estudio es el de aplicar teorías actuales sobre la instrucción y el aprendizaje del desarrollo de una lección diseñada para enseñar un concepto científico, usando técnicas de ingeniería, pidiéndole a los estudiantes que conciban soluciones para problemas del mundo real. Muchas investigaciones en este campo se han enfocado en estudiantes de secundaria. Esta investigación analizará la efectividad de estas técnicas didácticas en el nivel primario. Los resultados del estudio deberán ayudar a los docentes a mejorar su práctica y a aplicar teorías sensatas de aprendizaje en sus lecciones.

¿Qué se le pedirá a mi hijo(a) que haga?

Su hijo(a) participará de una lección en su sesión de campamento, llevada a cabo por un profesor voluntario de los Cub Scouts. La lección será una clase de ingeniería en la cual los estudiantes deberán construir y probar una solución para un determinado problema. Todos los estudiantes participaran en la lección normalmente, incluso aquellos que no tomen parte en el estudio. Su decisión de permitir que su hijo (a) participe en el estudio no afectará su experiencia en el campamento.

Si permite que su hijo (a) forme parte del estudio, se le pedirá que:

- Hable sobre sus pensamientos e ideas mientras realiza la tarea que se le ha asignado. Con su permiso, las interacción de su hijo(a) con el problema y la lección en general, serán grabados en audio.
- El investigador observará al alumnado, su interacción con la lección y entre

sí, y realizará preguntas informales diseñadas para inducir al estudiante a hablar sobre sus pensamientos durante la lección. Dicha lección tomará tres días de sesión; aproximadamente 45 minutos en cada una.

- Puede que se le pida a su hijo(a) que responda un par de preguntas sobre sus experiencias durante una breve entrevista personal con el investigador. Las preguntas se concentrarán en sus pensamientos y sentimientos sobre la clase, y sobre qué fue lo que le gustó o disgustó durante la misma. Las entrevistas no tendrán lugar durante el tiempo de clase y se harán en ocasiones como el receso, para que el día de clase del alumno no se vea afectado.

Esta investigación tomará tres días de sesión y habrá un máximo de 70 estudiantes en el estudio.

Puede que se grabe en audio a su hijo durante la entrevista y se realice la observación para propósitos de la investigación exclusivamente. La grabación no será usada por nadie más que el investigador; tampoco será hecha pública y será destruida en la conclusión del estudio.

No se prevén riesgos para la participación en este estudio.

¿Cuáles son los posibles beneficios de este estudio?

Su hijo no recibirá ningún beneficio directo por participar en este estudio. Sin embargo, la intención del mismo es ayudar a los docentes a mejorar su práctica profesional y proveerlos con los recursos necesarios para aplicar teorías pedagógicas y mejores métodos en sus clases de primaria, mejorando así la calidad de la instrucción en ese nivel.

¿Es necesario que participe mi hijo(a)?

No, la participación es voluntaria. Su estudiante puede decidir no participar, o retirarse del estudio cuando así lo desee. El retiro o negación de participar no afectará de ninguna manera su relación con la Universidad de Texas o con los Cub Scouts. Puede acceder ahora a que su hijo(a) participe en el estudio y cambiar de opinión luego, sin sufrir ninguna penalización.

Este estudio tendrá lugar durante sesiones regulares de actividad. Si su hijo(a) no quiere participar, no será observado o entrevistado. En ese caso, interactuará con sus compañeros y con su profesor, normalmente. No habrá penalización por no participar.

¿Qué pasa si mi hijo no quiere participar?

Además de su permiso, su estudiante debe acceder a participar en el estudio. Si no quiere participar, no será incluido en este y no habrá penalización. Si decide participar y después cambia de idea, puede renunciar sin que haya penalización.

¿Habrá alguna compensación?

Ni usted ni su estudiante recibirán pago alguno por su participación.

¿Cómo se protegerá la privacidad y la confidencialidad de mi hijo(a) si decide participar?

Se protegerá la privacidad y la confidencialidad de su hijo(a) por medio del anonimato. Ningún participante será identificado por su nombre o cualquier otra característica como género o etnia. Usaremos códigos para referirnos a los estudiantes. Cualquier característica individual, como ser el nombre en las grabaciones de audio, será destruida al finalizar el estudio.

Si se hace necesario para la Junta de Revisión Institucional examinar los registros, cualquier información vinculada con su estudiante será protegida hasta donde lo permita la ley. Los registros de su estudiante no serán hechos públicos sin su consentimiento, a menos que lo requiera la ley por medio de una orden judicial. Los datos obtenidos por medio de la participación de su estudiante serán puestos a disposición de otros investigadores para indagaciones futuras no detalladas en este formulario. En esos casos, los datos no contendrán ninguna información que permita identificar a los participantes.

Si elige participar en este estudio, puede que su hijo(a) sea grabado en audio. Dichas grabaciones serán guardadas de manera segura y solo el equipo de investigación tendrá acceso a ellas. Las grabaciones serán guardadas por cuatro meses y después destruidas.

¿A quién contacto con preguntas sobre el estudio?

Antes, durante o después del estudio, puede ponerse en contacto con Logan Pearce en persona, al xxx-xxx-xxxx, o mandar un email a xxx con preguntas o si siente que ha sido perjudicado. Este estudio ha sido revisado y aprobado por la Junta de Revisión Institucional de la universidad y el número del estudio es el **2014-03-0077.**

¿A quién contactar con preguntas sobre sus derechos como participante?

Para hacer preguntas sobre sus derechos o cualquier queja sobre cualquier parte del estudio, puede ponerse en contacto, de manera anónima si quiere, con la Junta de Revisión Institucional, al teléfono (512) 471-8871 o al email: orsc@uts.cc.utexas.edu.

Firma

Esta haciendo una decisión sobre permitir a su hijo(a) participar en este estudio. Su firma indica que ha leído la información contenida en las páginas anteriores y que ha decidido permitirle formar parte del estudio. Si después decide retirar su permiso para que su hijo(a) participe, puede descontinuar dicho permiso en cualquier momento. Se le proporcionará una copia de este documento.

__Mi hijo(a) puede ser grabado en audio.

__Mi hijo(a) NO puede ser grabado en audio

____

Nombre del estudiante en letra de molde

___________________________________ _______________

Firma del padre o guardián legal Fecha

___________________________________ _______________

Firma del investigador Fecha

Demographic questionnaire

The purpose of this questionnaire is solely to provide demographic information to the researcher. The information in this questionnaire will not be shared with anyone, and will not be used to identify any participants in the final study.

Name: ______________________________

Age: ________ Grade: ______________ Zip code: ____________ Number of years in Cub Scouts: _____________	How would you characterize your child's experience with building projects outside of Cub Scouts (circle one)? High Medium Low None Parent's occupation: _________________________________

Child Assent for Participation in Research

Title: Engaging Elementary Students in Active Learning Through Engineering

Introduction

You have been asked to be in a research study about learning science by doing engineering, or problem solving. This study was explained to your parent and they said that you could be in it if you want to. We are doing this study to see if children like to learn science this way, and if they have learned a lot by doing this type of lesson.

What am I going to be asked to do?

You will do a lesson with your class about science. In the lesson you will be given a problem to solve by building something. If you don't want to be in the study, you will still do the lesson with the other students.

If you agree to be in this study, you will also be asked to

- Talk with Ms Pearce about what you are thinking as you work on the problem.

- Answer some questions at the end about what you did, and what you learned.

What you say during the lesson and when you answer questions about your thoughts may be recorded, but only if you want to.

There are no dangers or things that could hurt you if you participate.

Do I have to do it?

No, you don't have to if you don't want to. You can even decide you want to be in the study now, and change your mind later. No one will be upset.

If you would like to participate write your name at the bottom and give it to Ms Pearce. You will get a copy of this page so if you want to you can look at it later.

Who will know about me being in the study?

No one. Whatever you say and do will be seen and heard only by your teacher and Ms Pearce.

If you decide you don't want to be in the study, your grade will not change, and your teacher will not be upset or disappointed. You should only say yes if you want to.

Who do I ask if I have questions?

If you have any questions about it, ask Ms Pearce, or ask your parents to send Ms Pearce an email with your question.

Signature

Writing your name on this page means that the page was read by or to you and that you agree to be in the study. If you have any questions before, after or during the study, ask the person in charge. If you decide to quit the study, all you have to do is tell the person in charge.

______________________________	____________________
Signature of Participant	Date

Teacher Consent for Participation in Research

Title: Engaging Elementary Students in Active Learning Through Engineering

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. The person performing the research will answer any of your questions. Read the information below and ask any questions you might have before deciding whether or not to take part. If you decide to be involved in this study, this form will be used to record your consent.

Purpose of the Study

You have been asked to participate in a research study about effectiveness of engineering lessons at the elementary level. The purpose of this study is to apply current instruction and learning theory to the development of a lesson designed to teach a science concept, by using engineering techniques, and requiring students to design and build actual solutions to real world problems. Much research in this area has been focused on the high school level student. This research will examine the effectiveness of these instructional techniques at elementary grades. The results of this research is intended to assist educators in improving their practice and applying sound learning theory to their classrooms.

What will you be asked to do?

If you agree to participate in this study, you will be asked to:

- Deliver an engineering lesson to your elementary aged campers. The lesson will be an engineering lesson in which students are given a problem for which they must build and test something to solve.
- The researcher will observe the classroom, observe student interactions with the lesson and each other, and ask informal questions designed to get the students to verbalize their thinking as they participate in the lesson. The researcher will observe your delivery of the lesson and interaction with students during the conduct of the lesson. The lesson will take 3 session days, approximately 45 minutes each.
- You may be asked to answer a few questions about your experience verbally in a one-on-one session with the researcher. Questions will be targeted to your thoughts and feelings about the lesson, how it was delivered, how it was implemented, your impressions of its effectiveness and value in your classroom, and what you liked/did not like about the experience. Formal interviews will take

place outside of class time, and so not impact your class day. The interview will take approximately 10-15 minutes and will be audio recorded.

You will be audio recorded during the interview for research purposes only. The recording will not be used by anyone other than the researcher, nor made public, and will be destroyed at the conclusion of the study.

What are the risks involved in this study?

There are no foreseeable risks to participating in this study.

What are the possible benefits of this study?

You will receive no direct benefit from participating in this study; however, the intent of this study is to assist educators in improving their professional practice, and to provide a resource for applying learning theory and best practices into their elementary classrooms, improving the quality of instruction in elementary classrooms.

Do you have to participate?

No, your participation is voluntary. You may decide not to participate at all or, if you start the study, you may withdraw at any time. Withdrawal or refusing to participate will not affect your relationship with The University of Texas at Austin (University) and Cub Scouts of America, Capital Area Chapter in anyway.

If you would like to participate please sign this form below and return it to the researcher. You will receive a copy of this form.

Will there be any compensation?

You will not receive any type of payment for participating in this study.

How will your privacy and confidentiality be protected if you participate in this research study?

Your privacy and the confidentiality of your data will be protected by anonymity. No participant will be identified by name, or any other identifying characteristic such as gender or ethnicity, in the course of the study. Participants will be referred to using a code. Any identifying characteristics, such as names and audio recordings, will be destroyed at the conclusion of the study.

If you choose to participate in this study, you may choose to be audio recorded. Any audio recordings will be stored securely and only the research team will have access to the recordings. Recordings will be kept for 4 months, until August, 2014, and then erased.

If it becomes necessary for the Institutional Review Board to review the study records, information that can be linked to you will be protected to the extent permitted by law. Your research records will not be released without your consent unless required by law or a court order. The data resulting from your participation may be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate it with you, or with your participation in any study.

Whom to contact with questions about the study?

Prior, during or after your participation you can contact the researcher Logan Pearce at xxx-xxx-xxxx or send an email to xxx for any questions or if you feel that you have been harmed. This study has been reviewed and approved by The University Institutional Review Board and the study number is **2014-03-0077**

Whom to contact with questions concerning your rights as a research participant?

For questions about your rights or any dissatisfaction with any part of this study, you can contact, anonymously if you wish, the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

Participation

If you agree to participate please sign this form below and return to the researcher, Logan Pearce

Signature

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

____

Printed Name

__________________________________ __________________

Signature Date

As a representative of this study, I have explained the purpose, procedures, benefits, and the risks involved in this research study.

____

Print Name of Person obtaining consent

__________________________________ __________________

Signature of Person obtaining consent

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