TEACHING PHYSICS USING PROJECT-BASED ENGINEERING CURRICULUM WITH A THEME OF ALTERNATIVE ENERGY

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ABSTRACT

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The Next Generation Science Standards (NGSS) provide a new set of science standards that, if adopted, shift the focus from content knowledge-based to skill-based education. Students will be expected to use science to investigate the natural world and solve problems using the engineering design process. The world also is facing an impending crisis related to climate, energy supply and use, and alternative energy development. Education has an opportunity to help provide the much needed paradigm shift from our current methods of providing the energy needs of society. The purpose of this research was to measure the effectiveness of a unit that accomplishes the following objectives: uses project-based learning to teach the engineering process and standards of the NGSS, addresses required content expectations of energy and electricity from the HSCE's, and provides students with scientific evidence behind issues (both environmental and social/economic) relating to the energy crisis and current dependence of fossil fuels as our primary energy source. The results of the research indicate that a physics unit can be designed to accomplish these objectives. The unit that was designed, implemented and reported here also shows that it was highly effective at improving students' science content knowledge, implementing the engineering design standards of the NGSS, while raising awareness, knowledge and motivations relating to climate and the energy crisis.

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Introduction

Overview

Science teachers today have an arduous task of balancing the ever-changing requirements and standards that are passed down from the state of Michigan. We all have a good idea of what our students will need to know to be successful in our respective subjects at the post-secondary level. As of 2015 the currently required Michigan High School Content Expectations (HSCE's) contain a lot of specific content knowledge our students are expected to learn. After realizing we also need our students to be able to think critically and solve problems, the science, technology, engineering, and mathematics (STEM) educators have shifted their thinking about standards to a new direction. The Next Generation Science Standards (NGSS) are currently being considered and could replace the current standards if adopted by the state of Michigan. They have a much narrower range of content knowledge and put more focus on engineering processes in science education. The NGSS seeks to ensure our students are ready to meet the challenges of the 21st century. It's not just what students know, but what they will be able to do that will contribute solutions to real global challenges.

With the graduate program for high school teachers offered through the College of Natural Science at Michigan State, participants were exposed to a very broad base of science knowledge with the goal of expanding areas of expertise of science teachers. The most useful element of the program were the Frontiers in Science sessions. Scientists from the university present cutting-edge research to teachers. Very few people outside of the world of academia are exposed to any of this information. Many of the presentations were related to research behind solutions to the effects of our current use of fossil fuels as a primary energy source. The research included current and long term effects of fossil fuel use on the environment, inability of fossil fuel reserves to meet growing energy demands, and the connection between energy production and consumption to human wealth and well-being. After learning about the current science and engineering research that was happening, this researcher became very passionate about teaching students the scientific data surrounding the hot topics of global climate change and use of fossil fuels. The general public's opinions on issues relating to these topics are often deeply held and politically charged. With so much debate and argumentation from both positions, it is not surprising that the general public's opinions do not reflect the scientific consensus and are based on information from media sources rather than peer-reviewed scientific work.

The purpose of this research was to determine whether a teacher can implement a unit that successfully addresses the currently required HSCE's, the shift in science education to the NGSS and STEM education, and to educate students and encourage passionate young adults to be concerned and informed about the energy crisis in a physics class. A redesigned energy unit is the perfect stage to accomplish all of this. Throughout any introductory level physics class, students first learn the basics of mechanics. The energy content expectations are unique because they are where physics branches off into other topics. The six forms of energy (mechanical, electrical, chemical, electromagnetic, thermal, and nuclear) all represent areas of study within physics. This is the crossroads of physics where other topics branch off (waves, sound, light, electricity, magnetism, quantum and modern physics, thermodynamics, and nuclear physics). A teacher could conceivably design units of instruction with a focus on energy and teach concepts of any of these topics.

Meaningful science education takes a great deal of time. Teachers have very limited time with students and a very extensive list of required objectives to cover. With new methods of science education constantly being developed, time is the limiting variable that decides what can be accomplished in class. Project-based engineering takes a great deal of time in class. Educating students about the many facets of the energy crisis including global climate change and renewable energies, while considered a very valuable experience, is not represented in current standards for any of the required high school courses (biology, chemistry, and physics). Time spent incorporating new ideas into a class takes instruction time away from other topics, and can lead to not covering all of the required content expectations. In order to add enrichment to the objectives being taught, a teacher must design curriculum that multitasks.

The curriculum presented here was designed and implemented with that goal. The purpose of this research was to measure the effectiveness of a unit that accomplishes the following objectives: uses project-based learning to teach the engineering process and standards of the NGSS, addresses required content expectations of energy and electricity from the HSCE's, and provides students with scientific evidence behind issues (both environmental and social/economic) relating to the energy crisis and current dependence of fossil fuels as our primary energy source. Energy education provides the "worldwide problem" required by the NGSS to be solved by the engineering process, as well as motivation for the students. Project-based engineering provides the opportunity to learn the science concepts of the HSCE's needed to accomplish the tasks. Designing the unit in a way that intertwines all three objectives allowed the time spent in the classroom to address all three objectives.

The Need for Engineering Education

The focus on STEM education has gained a lot of attention in the media and among educational institutions. Why has it become the current buzzword in education? "Rising concern about America's ability to maintain its competitive position in the global economy has renewed interest in science, technology, engineering and mathematics (STEM) education."

(Chen, 2009). 21st Century learners need to be prepared for new challenges. There is concern about our ability to cultivate enough highly skilled scientists and engineers to meet future demands.

A major question is whether this concern over skilled people in these areas is substantiated or just a perceived need. An ongoing public opinion research project commissioned by Bayer Corporation surveyed 150 talent recruiters at Fortune 1000 companies. The survey asked about the demand for 2 and 4-year STEM degrees compared to non-STEM degrees, and also about creation of STEM-related positions compared to non-STEM. 89% of talent recruiters identified 4-year STEM related degrees are "as/more" in demand than their counterparts. 73% of talent recruiters reported 2-year STEM degrees are "as/more" in demand. Only half of these Fortune 1000 recruiters say they can find adequate numbers of qualified job candidates with either 2-year or 4-year STEM degrees in a timely manner. 75% of Talent recruiters state that 10-years from now there will be more STEM job creation than non-STEM (Bayer Corporation, 2014).

A Carnegie Foundation commission in 2007 concluded that, "The nation's capacity to innovate for economic growth and the ability of American workers to thrive in the global economy depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility for young people that lie at the heart of the American dream." (Carnegie Corporation of New York Institute for Advanced Study Commision on Mathematics and Science Education, 2007).

The NGSS discuss the need for new science standards by noting a reduction of the U.S.'s competitive economic edge, lagging achievement of U.S. students, the need for preparation in STEM careers for the modern workforce, and scientific and technological literacy for an educated society. The NGSS argue that the current system of science and mathematics education is performing below par, and if left unattended, “Will leave millions of young Americans unprepared to succeed in a global economy.” (Next Generation Science Standards, 2015) According to recent studies, the United States education system is performing below par. The recently reported Third International Mathematics and Science Study, which compares performance in mathematics and science of 500,000 students worldwide, identified that U.S. students' performance was above average for fourth graders as compared to more than 21 other countries. However, by 12th grade, U.S. students perform near the bottom of industrialized nations (Brown, 1999).

Science, mathematics, and computer/technology credits are currently required as part of the graduation requirements in the State of Michigan. With three of these disciplines already well represented in high school courses, our biggest opportunity to improve STEM education is engineering education. The current curriculum based on the HSCE’s contain no engineering design standards. Furthermore, high-school students take science, math, and technology classes that are taught as isolated subjects with few connections made between the disciplines. Engineering courses are offered by very few high schools, and only as elective choices. With school districts facing major budget concerns, the ability to staff and equip a classroom for an engineering course becomes more of a pipedream than a realistic requirement. “For at least 50 years, imaginative teachers and engineers have attempted to introduce some form of engineering education into US high schools. But despite these sporadic efforts, only a small number of students have actually had such exposure.” (Industrial Research Institute Inc., 2009).

Many students are guided toward careers in engineering if they show promise in math and science in secondary education. Without an authentic experience of what engineering entails, how could they confidently choose engineering as a major? According to the U.S. National Science Foundation, enrollment in undergraduate engineering programs has dropped at a disturbing rate the past two decades, while the demand for engineers continues to rise (National Science Foundation, 2004). A statistical analysis designed to measure perspectives of engineering education among college students from 2008 reveals that college students, in general, feel that engineering is important and beneficial to society, however, it is difficult to obtain a degree in engineering and it leads to a demanding career (Li, McCoach, Swaminathan, & Tang, 2008). Furthermore, approximately one-half of engineering majors entering college complete degree requirements (French, Immekus, & Oakes, 2005).

This result could be from the engineering major not attracting stronger students, but also could be due to the fact that many students that choose, or are guided to engineering as a major, have had little experience in engineering and do not exactly know what engineering entails until they begin the program. Engineering experiences in secondary education could attract more interested students to the profession, and could also deter students who may choose engineering as a major but find out they are not interested in the work. This places a lot of importance on secondary teachers providing experiences that are both authentic and motivating for students. Simply put, if we as teachers are going to implement engineering at the high school level with limited resources, budgets, and experiences, it must be done well.

Implementing Engineering Education in the Classroom

There are a lot of benefits of approaching engineering standards by incorporating them into existing science courses rather than teaching them in stand-alone courses. This would cause teachers to rethink their subject matter. William S. Carlson from Cornell University argues that "technological design projects provide a sociologically fruitful approach to teaching new themes in science education" (Carlsen, 1998). A study from the University of Nevada in 2006 showed that students enrolled in integrated science courses that included an engineering design aspect had larger increases on standardized assessments than other students (Cantrell, 2006). The results of the study indicated that "Engaging students in engineering curriculum activities may diminish achievement gaps in science for some student populations."

Implementing Engineering in a secondary physics classroom lends itself well to a project-based learning (PBL) approach. The Buck Institute for Education defines PBL as, "A systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks." (Markham, Larmer, & Ravitz, 2003). PBL often involves peer collaboration, a strong emphasis on critical thinking and communication skills, and interdisciplinary learning (Lattimer & Riordin, 2011). For these reasons, PBL could inherently be more effective at scaffolding of learners with differing levels of ability through student collaboration. Traditional methods of teaching physics are not as well-suited to mixed-ability teaching, or developing group work skills. If the problems presented in the project are sufficiently complex, students must rely on each other to solve them. Delegation within groups can also motivate and keep students focused (Kampen, 2004). This approach facilitates students taking on an active role in constructing knowledge and engaging in inquiry and problem-solving skills.

For this research it is important to maintain the position that the purpose is, first and foremost, learning physics. PBL was used as a method to include engineering practices with a focus of alternative energies and climate change. Lattimer and Riordin (2011) claim that PBL often fails when the emphasis falls too heavily on the "project" element rather than the "learning". Projects that come at the end of a unit of study, are peripheral to core concepts, or are intended to demonstrate what has been learned rather than actively engage students in new learning might be fun but fail to engage students in meaningful learning. Wiggins and McTighe label this as the "sin of activity-oriented teaching" in their *Understanding by Design Guide to Creating High-Quality Units* (p. 8). Teachers plan and conduct activities to be engaging but the approach often confuses "hands-on work with minds-on work" (Wiggins & McTighe, 2011).

John Larmer and John R. Mergendoller (2010) suggest two criteria to ensure project-based learning is meaningful. First, students must perceive the work as personally meaningful, as a task that matters and that they want to do well. Second, a meaningful project fulfills an educational purpose. They also suggest that the project should include a publicly presented product arguing that students care more about the quality of their work when presenting to a public audience. Barren et al. describe a study done by Petrosino in which he found students learned very little while performing a rocket building project for a competition (Petrosino, 1998). Petrosino modified the project to enhance the use of the scientific method by adding a "learning appropriate goal". In the new version, the students submitted design plans with specification to the National Aeronautics and Space Administration for a rocket kit to be used by many schools. Exit interviews showed that students with the enhanced conditions learned more about rocketry and controlled experimentation (Barron et al., 1998).

Students in a secondary science classroom should have experiences with controlled experimentation. The addition of engineering design practices should work synergistically with scientific work performed in the class and not replace it. A combination would allow the opportunity for students to compare and contrast the work of both professions. The Learning by Design ™ (LBD) framework is a project-based inquiry approach with roots in case-based reasoning and problem-based learning (Kolodner et al., 2003). The approach blends design/redesign activities with explore/investigate activities. The investigations become concepts they "need to know" to develop what they "need to do" for the design (Brophy, 2008). This approach shows how project-based engineering design activities can be linked to science content and investigations to provide students authentic experiences in both disciplines.

A Framework for K-12 Science Education released by the National Research Council (2012) provides the foundation for which the NGSS was based. The *Framework* includes engineering practices that should be used in science classrooms to facilitate successful implementation of the engineering standards. The eight science and engineering practices that the *Framework* indicate are "essential for all students to learn and describe in detail" are listed below: (Next Generation Science Standards, 2014)

1. Asking question (for science) and defining problems (for engineers)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in arguments from evidence
8. Obtaining, evaluating, and communicating information.

The rationale for why these practices are essential is explained in chapter 3 of the *Framework*: "Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science." (National Research Council, 2012) These practices provide teachers with ways to be sure they are effectively engaging students in practices that will provide meaningful learning of science and engineering practices in their course. They also provide a basis for which the research reported here was developed and implemented to achieve.

The Need for Alternative Energy and Climate Change Education

A frustrating gap exists between the scientific consensus of global climate change and public opinion. Research published in 2013 found that among peer-reviewed papers stating a position on anthropogenic global warming, over 97% endorsed the consensus that humans were causing climate change. Meanwhile the public think there is a 50:50 debate among climate scientists (Cook, 2013). A National Academy of Sciences report states that, "The scientific understanding of climate change is now sufficiently clear to begin taking steps to prepare for climate change and to slow it." (The National Academies, 2008). Robert Brulle and his colleagues performed an empirical analysis of the factors that affect U.S. public concern on climate change and found that media coverage imparts an important influence, however the coverage itself is a function of cues from the political elite and advocacy groups. The report showed that circulation of scientific information to the public has minimal effect (Brulle, Carmichael, & Jenkins, 2012). According to Brulle et al, "Public opinion regarding climate change is likely to remain divided as long as the political elites send out conflicting messages on this issue." Greater efforts are needed to educate the public in the sciences of climate change (Contribution of Working Group II, 2007).

As science educators we have an opportunity to help our students who will soon become the "general public" to approach all information with a healthy dose of skepticism and to put more trust in the scientific process that can expose misinformation. Our students are growing up in an age where information is everywhere. Showing our students the scientific information alone may have a minimal effect, but including education of the scientific process and how peer-reviewed scientific information differs in accountability from "expert" opinions propagated through media channels could provide a much needed paradigm shift of how the "general public" discerns information they base their opinions on.

Climate change and alternative energy education implemented in secondary education has the opportunity to increase awareness about the climate and energy use and supply issues. Energy is the basis of a modern standard of living. Conventional energy education has also generally failed to provide basic understanding about issues relevant to energy supply, its use, and energy–environment interaction. In their case study in Pakistan, Mirza, Harijan, & Majeed (2012) state that the recent surge of growth in the alternative energy industry has caught educators off-guard. They also recommend a solution, "By understanding the role of education in the growth of renewable energy, appropriate programs can be developed to address the needs of industry and the community."

In the past, science education centered on cultural change has fallen short of creating desired changes. For example, Rosalyn McKeown and Charles Hopkins (2010) claim that sex education focused on anatomy has not necessarily lowered teen pregnancy rates. Also, education of toxic and carcinogenic components of tobacco have not reduced the number of smokers. They also argue that climate change has social, economic, environmental and political roots and that climate change education should reflect that complexity. In their paper, *Rethinking Climate Change Education*, they claim that climate change can be successfully taught: "We know from years of experience in environmental education that knowledge and awareness alone do not bring about large-scale societal change. However, education that includes awareness, knowledge, skills, values, and opportunities for participation does bring about in-depth learning and behavior change." To accomplish the desired behavior change in students, it seems awareness and values of the social, economic and political components of the issue, which would traditionally not be taught within physics curriculum, are just as important to include as the knowledge and skill-based components.

School Demographics

The research reported here took place in a Physics course at Stockbridge High School. Stockbridge is located in the southeast corner of Ingham County. The area is very rural, consisting of mostly farmland. The school district includes areas of Ingham, Livingston, Washtenaw, and Jackson Counties. Stockbridge High School had a total of 581 students in the 2014-2015 school year. Of those students 177 (30%) are labeled as economically disadvantaged. The district is not ethnically diverse with 551 white, 24 Hispanic/Latino and 4 African-American students. The eighth grade was brought up to the high school building in 2014 when the middle school was closed and grades were re-aligned. The High School runs a 4 x 4 block schedule where students take 4 courses each semester that meet for 90 minutes every day.

There are four science teachers in the high school building. All students take Earth Science in 8^{th} grade and Biology as ninth graders. Students then take either Chemistry 1 or Applied Chemistry. Applied Chemistry is team-taught with a special education teacher. In the 2014-2015 year there were four sections of Chemistry 1 and one section of Applied Chemistry. All students then take either Applied Physics or Physics 1 as their third high school science credit typically in 11^{th} grade. There were four sections of Physics 1 and one section of Applied Physics in 2014-2015. The high school also offers AP Biology, AP Physics, Chemistry II, Wildlife Biology, and Anatomy & Physiology as science electives.

The research reported here took place in two sections of Physics I offered in the first semester of the 2014-2015 school year. While sections of the course typically average 25-30 students per class, the two sections taught during this research only had 16 and 21 students. The course is designed to be an introductory level physics course to meet all students' skill level, while maintaining the rigor of a college-prep physics course.

Implementation

In order to implement research on high-school students, a consent process was implemented to collect classroom artifacts generated by minors. A consent form (Appendix A) was developed, explaining the study and the process of collecting, storing, and reporting data. A sealed envelope was provided with the forms and students were instructed to place the form in the sealed envelope and place it into a sealed box located in the teacher's classroom. The box and envelopes were not opened until after the course was completed and final grades were assigned.

Reorganization of the Course

The Physics 1 course on which this research was based was previously broken up into nine units, each requiring about two weeks of instruction: Unit 1: *Science & Measurement*, Unit 2: *1-D Motion*, Unit 3: *2-D Motion*, Unit 4: *Forces*, Unit 5: *Gravitation and Rotation*, Unit 6: *Impulse & Momentum*, Unit 7: *Work, Power and Energy*, Unit 8: *Waves, Sound and Light*, Unit 9: *Electricity and Magnetism*. To make room for new curriculum, *Impulse & Momentum* was combined with the *Forces* unit, *Work, Power & Mechanical Energy* form a unit, and the unit upon which the research was done was a combination of *Energy and Electricity*. This format allowed coverage of the required HSCE's while making room for longer term engineering projects related to energy and electricity concepts. This format also allowed a focus on energy and the opportunity to teach alternative energies while covering the required content expectations. Table 1 displays the sequence of activities designed for this unit. The objectives of each activity are also included.

Table 1: Sequence of activities designed and implemented during unit

	Activity	Objectives (Students will)
1	Energy Powerpoint® presentation	➢ Identify the 6 forms of energy ➢ Explore nuclear energy ➢ Describe how power plants work ➢ Create energy transformation diagrams ➢ Discuss efficiency and energy "loss"
2	Energy Transformation Lab	➢ Identify forms of energy present in devices ➢ Create energy transformation diagrams
3	Greenhouse in a beaker lab	➢ Perform controlled experiments to observe the greenhouse effect
4	*Cosmos* season 1 episode 9	➢ Observe changes in climate in the past and the results of those changes ➢ Identify how fossil fuel reserves built up on Earth in Carboniferous period ➢ Observe how the scientific process works and what data lead to our understanding of these changes in geological history
5	*Cosmos* season 1 episode 12	➢ Explore numerous indicators of humans effect on the environment through fossil fuel use ➢ See the scientific data that forms the evidence and how it was collected ➢ Differentiate between climate and weather ➢ Make predictions about what could happen unless changes are made
6	Energy use/supply and Climate data exploration and presentation	➢ Explore the connection of energy and human wealth and well-being ➢ Analyze data and interpret results ➢ Realize the current state of energy supply and use and the realization of the energy crisis
7	Energy Articles Activity and Assignment	➢ Compare peer-reviewed scientific work to information portrayed in the made ➢ Find sources (articles) and critique arguments made about climate change or energy use/supply ➢ Identify possible bias that may exist
8	Exploring Wind Design Project	➢ Use Engineering Design Process ➢ Conduct controlled experiments (Wind investigations) to aid in design ➢ Perform energy and electricity calculations to evaluate performance
9	Energy Calculation practice Ohm's law notes/assignment	➢ Used during wind design project to aid students in performing energy calculations with simple circuits

Table 1: (cont'd)

10	Wind farm design / Presentation	➢ Research social, cultural, and environmental impacts to prioritize criteria and constraints of design ➢ Use computer models to perform cost analysis of design ➢ Publicly present designed wind farm
11	Exploring Solar Power Activity / Assignment	➢ Perform inquiry investigations to investigate solar power and the effect of series and parallel circuits on voltage and current ➢ Practice wiring solar arrays to produce desired voltage and current output

Activities Designed for this Study

Unit 7 began with a PowerPoint® presentation covering the 6 forms of energy (mechanical, electrical, electromagnetic, chemical, thermal and nuclear). The presentation defined each type and gave numerous examples. The initial focus was on students identifying the types of energy around them and naming them properly. While covering nuclear energy, students investigated the mass-energy relationship by finding the mass difference in nuclear fusion and fission reactions and calculating the energy using $E=mc^2$. The nuclear chain reaction was investigated and applications in weapons and reactors were discussed.

The next half of the PowerPoint® addressed conservation of energy. Students must understand that energy comes from energy. Students made energy transformation diagrams of common items or devices. The concept of efficiency was also introduced and applied to examples. The energy transformation involved in power plant operation was also presented. The students were given homework to reinforce these basic energy concepts.

An *Energy Transformation* (Appendix B) lab followed. Each of six stations had different items placed on them that undergo forms of energy transfer. The students' task was to identify the forms of energy, then draw an energy transformation diagram showing the energy transfers that occurred with each item. Some of the devices included a: cordless drill, solar-powered car, hand-crank generator connected to light bulbs and capacitor, model St. Louis electric motor, thermopile generator, hand boiler, striking a match and burning a small tortilla chip, large ball bearings (when smashed together on paper they burn a hole in paper), electric radio/alarm clock, flashlight, and others.

The unit shifted to a larger scale understanding of energy. The goal of the next few activities was for students to interpret the scientific data behind global climate change and gain a better understanding of how energy is currently produced and used. Additionally, students were to realize the importance of affordable energy on wealth and well-being, explore actual data behind the supply and demand of energy and future predictions, understand the existence and explore possible causes of the discrepancy between scientific consensus and public opinion, and ultimately form their own educated opinions about all of these topics.

The *Greenhouse in a Beaker Lab* (Appendix C) was slightly modified from a National Energy Education Development Project (NEED) publication titled *Exploring Climate Change*. Students were able to see the temperature difference the CO_2 caused in the beaker as shown in Figure 1. Sample student data are shown in Figure 2. The concept was then reinforced using a University of Colorado Boulder simulation from the PhET website (http://phet.colorado.edu/en/simulation/greenhouse). Greenhouse gases other than CO_2 were explored. The simulation also allowed students to see the large scale effect on the planet by observing the sun warming the earth and manipulating the greenhouse gas concentration and cloud cover and observing the change in temperature at the surface.

Figure 1: Students performing *Greenhouse in a Beaker Lab*

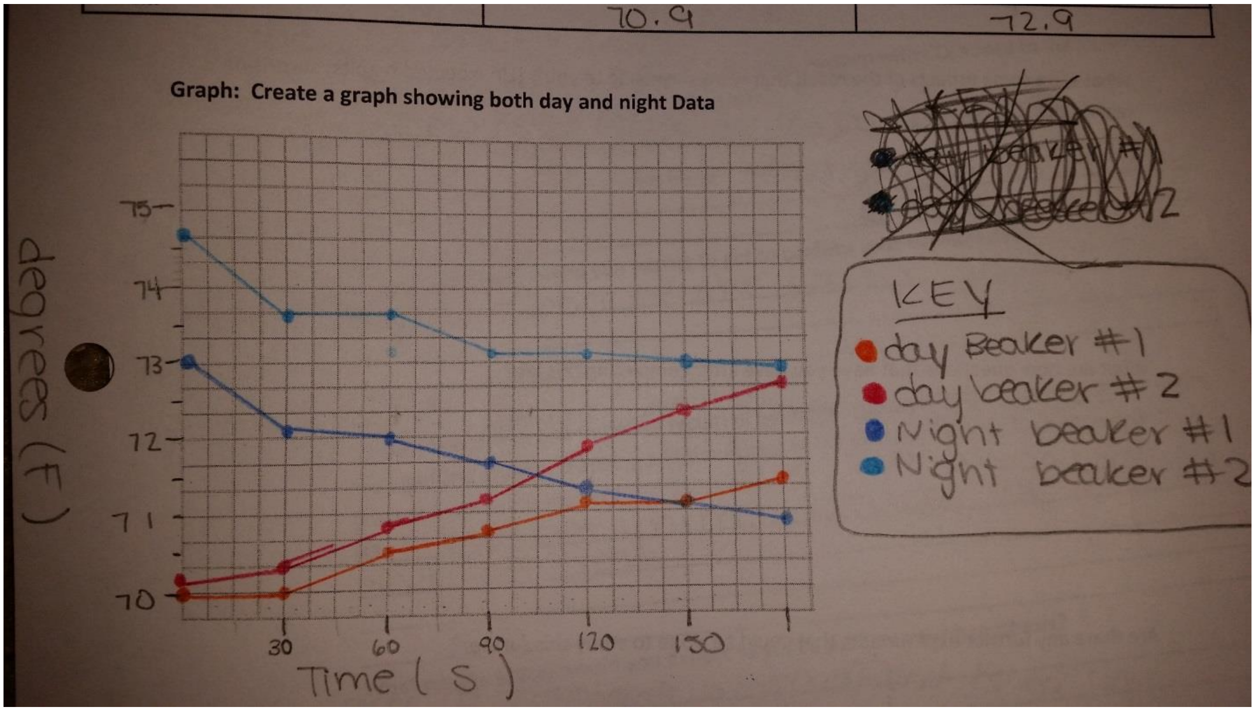

Figure 2: Sample student data from *Greenhouse in a Beaker Lab*

To explore the consequences of the greenhouse effect on Earth, two episodes of *Cosmos: A Spacetime Odyssey* were shown to students. They were provided handouts to use during the videos (Appendix D) that were found at http://evolution.about.com/od/Cosmos-Teaching-Tools/fl/Cosmos-Episode-9-Viewing-Worksheet.htm. The episodes were paused to answer questions and reinforce ideas. Episode nine from season one "*The Lost World of Planet Earth*" explored the geological, and biological history of Earth and showed the impact on the development of life on Earth caused by dramatic changes in climate in the past. The causes of those changes in climate as well as the consequences were also explored. Students learned about the carboniferous period and how and why fossil fuel reserves built up on Earth. In the episode students saw how the scientific process works over time.

The greenhouse effect due to human activity was also explored in episode twelve of season one "*The World Set Free"* which presents scientific evidence of humanity's influence on climate change. The existence of positive feedback loops were investigated and the possibility of a runaway greenhouse effect was introduced. The episode also shows alternative forms of energy introduced by entrepreneurs as early as the 19^{th} century and how those forms were ultimately abandoned as fossil fuels were abundant and affordable.

The Frontiers in Science sessions that inspired the work reported here also provided a lot of useful information, primarily data, and graphs from those presenters (Appendix E) for students to use in the discussion that followed. Some data were reinforcement of what students learned in the *Cosmos* episodes, while some data presented material new to the students about fossil fuel use, supply and the connection to human wealth and well-being.

At this point students were asked why there is so much debate on what to do, if we need to do anything, or if there is a climate change and energy supply problem at all? As a class we looked at four different articles taken from internet media sources to explore the problem. The sources were all cited and accessed within a day or two of the activity. Two articles were chosen from each position of global climate change/energy crisis. Students read the article and then we evaluated the claims the writers were making and investigated any bias that might exist. The activity was designed to show students how scientists are held accountable for their claims by other scientists and how the process exposes incorrect or misleading conclusions and arguments. However, journalists are held accountable for claims they make only by their employers and ultimately the readers. The activity had students consider how scientific facts can be accurate in an article, but used or spun in certain ways. For example, in one of the articles a claim was made that "CO2 is not a significant greenhouse gas; 95% of the contribution is due to water vapor" (Staff, 2014). It is accurate that water vapor is a large contributor to the greenhouse effect, however, human activity is not causing an increase, unless you consider increased evaporation rates caused by a rising global temperature.

The analysis encouraged students to be just as critical of unsupported and spun claims made by authors with a pro climate change position. The objective of the activity was for students to be more skeptical of what they read and also to illustrate how this can lead to such a large disconnect in scientific and public opinion. Students were assigned homework (*Climate Change Articles Homework*, Appendix F) where they were to find four articles on their own and analyze them in the same ways.

The major activity in this unit was the engineering process adopted from NASA, which includes eight steps (Figure 5 in Appendix G). A template was made (Appendix G) to provide students with a guide to help them navigate the process. Each step was included on the template along with bulleted notes about what each step includes and how students were to accomplish each step. The template also included bolded check marks which are required items in their engineering design write up.

The stage was set for the *Exploring Wind Design Project* (Appendix H) since students had the necessary background information and motivations for learning about alternative energies. To manage the group work in the engineering project, students were placed in groups of three or four students chosen by the teacher based on their strengths and weaknesses. The students became employees of an engineering firm. The teacher became the owner/general manager of the firm. A fictitious company, The Michigan Energy Corporation, has hired the firm to help them design wind turbines to implement wind power in the state. They were to use the engineering process, and template provided, to design and build a wind turbine that meet some basic criteria. The students were then given the task of assigning a specific role to each person within the group. The roles were:

> **Scientist** – in charge of all content knowledge related things
>
> **Project Manager** – In charge of facilitating discussion and delegating tasks. Held accountable for any and all off-task behavior.
>
> **Lead Engineer** – In charge of design/construction and building related tasks.
>
> **Communication Manager** (if four members in group) – Takes lead responsibility for organizing/presenting information.

The project managers report directly to the teacher. If any off-task or unacceptable behavior was observed, the project manager was held accountable. If any student was not upholding their responsibilities in the group they could be fired by their group. Concerns must first have been brought to the general manager (teacher), who then met with the individual. A performance management plan was developed to correct the problem. If improvement did not occur the student could be fired. Any student fired must either complete the entire project alone, or reapply and interview for their old position.

The student engineering groups were given the *Exploring Wind Design Project* handout (Appendix H). The project was developed by the researcher to meet the four engineering standards of the NGSS (Appendix I). The students engaged in activities that had them analyze a major global challenge, specify qualitative and quantitative criteria, design solutions through engineering by breaking it down into small, manageable problem, evaluate the solution based on prioritized criteria, and model the performance using physical models and mathematical modeling. The project also addressed several required physics HSCE's relating to energy, electricity and the scientific process standards (Appendix J).

The students were provided with a benchmark blade template from the *Exploring Wind Teacher Guide* available from NEED Project's website (www.need.org/secondary). A basic tool kit was assembled for each station and included: cardboard, ¼" dowel rods, small saws, heavy wire cutters, duct tape, masking tape, packing tape, rulers, a blade pitch protractor and KidWind turbine hub (purchased from www.verner.com), utility knife, scissors, hotglue gun, pennies and a balance to use in construction of their blades.

The students were instructed to work up to step three (Brainstorming/Ideation) of the engineering template. As students worked through the engineering process they were documenting their work in the *Exploring Wind Design Project* handout. As they got to step three they received the *Wind Turbine Blade Investigations* handout (Appendix K). The investigations were modified from the NEED Project's *Exploring Wind Student Guide*. Students used the provided materials to complete five controlled experiments to research the variables that affect the performance of their turbine blades. The investigations were to explore: blade pitch, number of blades, surface area of blades, and mass of blades. Students also calculated power from wind using a wind-speed meter which allowed an efficiency calculation by comparing the electrical power produced by their blades. Additionally, the students did research on how concepts of torque, drag, and Bernoulli's principle affect blade design from pages 14-17 of NEED Project's student guide. For each experiment, students formed hypotheses, choose how to test the variable, took data, constructed graphs, and formed conclusions. The optimum blades from their investigation then became the control for the next investigation.

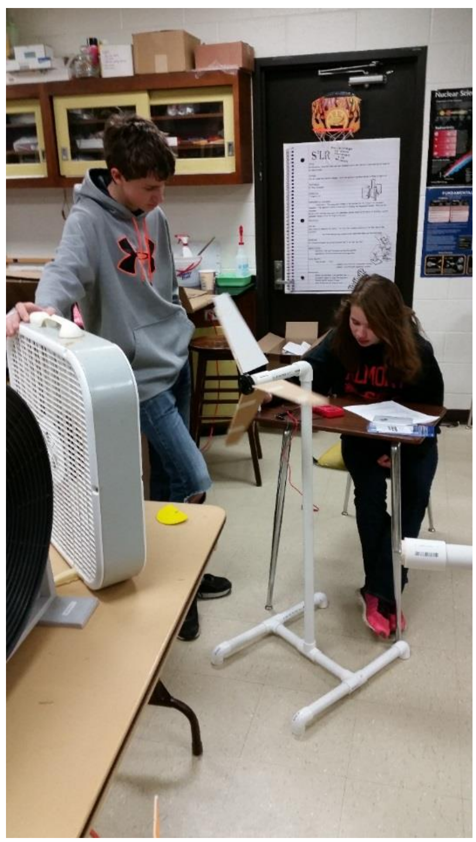

Figure 3: Model turbine and blade testing station

Three testing stations for the investigations were setup using a model turbine constructed from PVC pipe and electric motor inserted into the end, and a standard box fan as shown in

Figure 3. Students were able to press-fit their hub and blade assembly to the motor's shaft and take voltage measurements to measure the performance of their blades using a multi-meter.

Students worked through steps 3-5 of the design process where they brainstormed ideas to construct their own blades, provided sketches of top 3 or 4 options and listed the pros and cons of each design. Students completed a decision matrix (sample found in *Engineering Design Template*, Appendix G) where they broke down the design into the top 3-5 constraints and assigned a number to each design representing how well it would meet that constraint. The highest scoring design from their matrix became the plan for their first prototype.

To support the next phase of the project students were given notes in a lecture format on energy and electrical power and example calculations were done in class. Students were assigned related homework (*Energy and Power Practice* Appendix L). Once the prototype blades were constructed by students they measured the voltage produced by blades alone, the voltage and current when the leads were connected to a 10 Ohm resistor, and were able to calculate the electrical power produced by their blades. They were also able to do efficiency calculations by comparing the power of the wind at the controlled distance and fan setting (from investigations) to the electrical power their blades produce. The students documented the performance in step seven of the handout and noted any changes they would like to make to refine their design. The final step of the blade construction for students to refine their prototype and test the performance of their final product in the same way.

The next phase of the project was designed to further the engineering process of communicating results. The remaining engineering standards of the NGSS were also addressed including: accounting for societal needs and wants in their design, cost analysis, accounting for social, cultural, and environmental impacts, and using computer simulations to model the impact of proposed solutions.

Students were provided with the *Communicate Results* handout (Appendix M). The students were given the task of preparing a presentation to the fictitious energy company of the design process and final product. Their presentation needed to include mathematical modeling of the full-scale performance of their turbine blades. The scenario was taken a step further by telling students that the federal government was willing to subsidize a 9.3 billion dollar loan to the company with the best plan to implement wind power in their state. The number was chosen because it represents only 10% of the reported profits from the top five oil companies from 2013 (Peterson, 2014). The student teams were given the task of designing wind farms in Michigan using the subsidized loan. The students were also to account for a wide range of societal needs and wants. In summary, there were three main aspects of the student presentations (mathematical modeling of full-scale blade design, computer modeling of wind farm performance in Michigan, and the siting a wind farm activity accounting for societal needs and wants).

The *Siting a Wind Farm* activity adapted from NEED was completed by groups in the classroom using student provided laptops. The students were given various roles to explore with a short description of aspects of a wind farm they might be concerned with. The roles included: developer, investor, farmer/rancher, neighbor/consumer, environmentalist, and others (Appendix M). Students were given some useful websites to read about the general pros and cons of wind power and encouraged to come up with their own as well.

The implementation of the wind farm design portion of the presentation also required use of a computer lab. Students were provided with a help sheet with required websites to use for the design process. Students used the energy mapping system found on the Energy Information Act (EIA) website (http://www.eia.gov/state/maps.cfm?src=home-f3). This system provided information on energy related resources for the entire country. The students selected the Michigan map and removed all filters except for wind power plants and on-shore/off-shore wind potential. The map provided locations of wind turbines currently in use and even allowed students to click on a turbine and acquire relevant information about that specific turbine. Students were given the task of finding areas in Michigan where the wind-speed potential was high enough to make building a wind farm economically feasible. Additional parameters were a location where wind power was not in use, and where the construction of a new farm would be the least restrictive to the societal needs and concerns explored in the *Siting a Wind Farm* activity.

The students were provided with a *Wind Farm Calculator* spreadsheet (Appendix N) to model the cost and environmental impact of constructing a wind farm. The spreadsheet was developed by this researcher to give students an opportunity to look up authentic information with provided links, regarding Michigan energy use and the costs involved in building and maintaining a wind farm. Students also perform complex cost analysis of building multiple turbines. The formulas built into the spreadsheet allowed students to model the performance without the advanced math skills required to come with the calculations on their own.

Upon completion of the three main aspects of the *Communicate Results* (Appendix M) activity (mathematical modeling of full-scale performance, siting a wind farm activity, and designing a wind farm using computer modeling), the students were given one week to finish their presentations.

During the week students were completing their presentations outside of class time, the energy unit continued with an exploration of solar power. Students were given notes and demonstrations of Ohm's law in class and completed *Ohm's Law Homework* (Appendix O). Series and parallel circuits and their effect on current and voltage within a circuit were also covered in class. The students then completed the *Exploring Solar Power* activity (Appendix P) where they used small photovoltaic cell arrays to investigate how wiring the array in series and parallel affects the output of the array. The exploring solar power activity was also modified from the NEED Project's *Photovoltaics Student Guide* available from their website (www.need.org). Upon completion of the lab activity, the students completed the *Wiring Solar Panels* worksheet (Appendix Q) for homework.

The original plan by the researcher was to include an additional exploration of hydroelectric power. The hydroelectricity project was similarly setup to the wind project. Students were to complete investigations of hydropower by building a turbine out of 2 gallon water jugs and designing rotor blades that fit inside. Students were to test their blades, measure the potential energy of an elevated water source, measure the power of the flowing water from the elevated source, and investigate electromagnetic induction by experimenting with magnetic fields produced by coils of wire. The students were to make their generators from scratch using wire and magnets to use with their turbine and follow the same engineering template designed for the wind power project. The presentation aspect of this project was also similar to that of the wind turbine project. Unfortunately, for a variety of reasons, time ran out for the semester and the hydroelectricity project had to be sacrificed.

Assessments

There were numerous objectives of this unit. The objectives can be grouped into 4 categories: climate, engineering, energy, and electricity. A separate assessment was developed for each of the main objectives to measure how well the unit addressed each of them. Students were given pre-assessments for use as comparisons before the unit began. The same test was then given after the students had completed the material designed to address that objective. Some of the post-assessments were given during the unit for that reason rather than administering them all at the end of the study.

Climate Change Survey (Appendix R)

This assessment addressed the goal of the researcher to improve students' scientific knowledge and to inspire passionate young people who are educated about the issues surrounding global climate change. The assessment contained survey questions that had students rate their belief regarding a certain statement from a 1-5 scale with 1 being strongly disagree, and 5 being strongly agree. There was also an "I don't know" option given to students if they felt they didn't have the necessary knowledge to take a position on the statement. Many of the questions involved common misconceptions or positions about the issues that are seen in articles and news programs. The survey also asked students to rate how much they trust information about climate change from different sources. If the unit was successful as intended by the researcher, there should be a shift toward agreement for the scientifically supported statements, and a shift toward disagreement of the common misconceptions or scientifically inaccurate statements. There should also be evidence of higher motivations in doing something about the problem. The last question on the survey was to see if students get the big idea of how they affect climate change by simple choices they make in their daily lives. The survey was given as a post-assessment at the beginning of the wind power project.

Energy Pre/Post Test (Appendix S)

The energy assessment consisted of 7 short answer and 7 survey questions. The short answer questions were designed to see how well the unit addressed energy concepts required by the Michigan standards (HSCE's). Students should know the forms of energy, conservation of energy, where energy comes from, how to draw transformation diagrams, and define efficiency. If the unit was successful the assessments should also show students making mature connections between quality of life and affordable energy. Students should be able to list multiple reasons why it is important to develop alternative energy sources. The survey questions asked students about their agreement of statements about fossil fuels and alternative energies. Questions also measured students' agreement with statements relating to the supply of fossil fuels, if alternative energies are feasible replacements, should we pursue them now, and their motivation for looking at articles or new stories about energy.

Engineering Design Pre-Assessment/Post Assessment (Appendix T)

The engineering design pre assessment asked students about what scientists and engineers do to see if they can distinguish between them. It also measured their opinion about their knowledge of the engineering process and what an engineer does, whether they are interested in engineering and if they feel engineers are important to the future of society. The post assessment asked the same questions but also measured how effective the unit was at implementing the four NGSS Engineering Design Standards (Appendix I). Students should be able to describe where in the unit they engaged in the practices contained within the standards.

Electricity Assessment (Appendix U)

The electricity assessment was given to students to measure how well they learned the electricity science content while engaging in the engineering projects and supporting classwork. The assessment asked them to respond with what they know about current, resistance, voltage, Ohm's law, power, energy, and a basic analysis of series and parallel circuits. This assessment indicated whether the unit was successful at teaching students the science content required by the HSCE's. A question about alternating and direct current was not applicable since it was addressed during the hydropower project that was omitted.

Results

The *Climate Change Survey* results are shown in Tables 2 through 5. The analysis showed averages of student responses (n=34). For statistical analysis, averages on all assessments were compared using a paired, single tailed t-test. The results were considered statistically significant if the p-value was less than 0.05. The survey showed a shift in class averages for each response to the survey questions. For the survey, the responses are a spectrum that show agreement with each statement. A response of 1 indicates strong disagreement, and a response of 5 indicates strong agreement with the statement. A response of 3 indicates that the student neither agreed nor disagreed with the statement. The students were also given the option of choosing "I don't know". They were instructed to use this option if felt they had no basis to answer the question or didn't understand it. During the pre-test, of all student responses, 79 questions were answered with "I don't know". During the post-test, only 28 questions were answered with "I don't know". The results shaded dark grey showed no significant change based on statistical analysis and will be discussed in the discussion section.

Table 2: Class averages of student responses on *Climate Change Survey*.

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**
Pre-Test Average	3.565	4.452	2.000	3.969	2.375	4.241	2.571
Post-Test Average	4.452	4.706	1.758	4.455	1.912	4.485	1.906
P Value	0.001	0.042	0.043	0.023	0.022	0.044	0.038
	Q8	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**
Pre-Test Average	3.042	3.857	4.040	2.379	3.100	3.483	2.667
Post-Test Average	2.500	4.161	4.313	2.147	1.933	4.242	3.176
P Value	0.112	0.074	0.198	0.201	0.000	0.001	0.023
	Q15	**Q16**	**Q17**	**Q18**	**Q20**		
Pre-Test Average	3.656	3.000	2.765	3.323	0.324		
Post-Test Average	4.242	3.676	2.424	4.212	1.227		
P Value	0.002	0.000	0.108	0.001	0.000		

The results showed a significant shift toward strong agreement with statements that show an increase in knowledge of the science content involved with global climate change. The results showed a significant shift toward strong disagreements with many statements that indicate common misconceptions about climate change. To more clearly display the data and summarize the results, Tables 3 and 4 show the statements to which the student average shifted toward strong agreement and disagreement respectively.

Table 3: Statements with significant shift toward strong agreement

	Significant shift toward strong agreement from *Climate Change Survey*
Question #	**Statement**
1	Carbon dioxide levels in the atmosphere prevent some of the sun's energy from radiating into space.
2	Burning of fossil fuels releases carbon dioxide and other gases into the atmosphere.
4	The Earth goes through natural cycles of heating and cooling over the course of millions of years.
6	Assuming global warming/climate change is happening, it is very likely affected by humans.
14	If I come across information about climate change I tend to look at it.
15	Decisions and actions I make every day can contribute to climate change.
16	I feel a moral duty to do something about climate change.
18	I feel I am educated enough to form my own opinion about global climate change.

Table 4: Statements with significant shift toward strong disagreement

	Significant shift toward strong disagreement from *Climate Change Survey*
Question #	**Statement**
3	The Earth's atmosphere is large enough where human activity cannot possibly cause a significant change.
5	I am unsure if global warming/climate change is happening.
7	The evidence for climate change is unreliable.
12	The last winter was one of the coldest on record. This is evidence against global warming/climate change.

Table 5 shows averages in the level of trust that students put in information about climate change coming from various sources (n=34). The results showed a significant increase in the level of trust students would put in information coming from a scientist and a distrust in information coming from the media. The results shaded dark grey showed no significant difference based on statistical analysis. The data showed that students overall had in increase in skepticism about climate change information from the media, and significantly more trust in scientific data.

Table 5: Averages of student responses to Question 19 of *Climate Change Survey*.

Question 19	Family/Friend	Scientist	Government
Pre-Test Average	2.618	1.424	2.618
Post-Test Average	2.765	1.147	2.882
P Value	0.141	0.013	0.106
Question 19	**Energy Supplier**	**Environmental Organization**	**Media**
Pre-Test Average	2.303	1.576	3.118
Post-Test Average	2.290	1.765	3.471
P Value	0.369	0.064	0.010

Tables 6 & 7 contain the class average data for the *Engineering Assessment* (n=34). The post-assessment includes five additional questions not found on the pre-assessment. Four of these correspond to the engineering standards found in the NGSS and question 7 asked students to identify science concepts used during engineering projects. Questions 3-5 became questions 8-10 on the posttest due to the insertion of the additional questions. The results shaded dark grey showed no significant change based on statistical analysis and will be discussed in the discussion section.

Table 6: Class average data for *Engineering Pre/Post Assessments*

	Q1	Q2	Q3/Q8	Q4/Q9	Q5/Q10
Pre-Test Average	0.54	0.22	2.77	2.97	4.30
Post-Test Average	0.74	0.71	4.23	3.23	4.97
P Value	0.19	1.06E-04	3.06E-06	0.17	2.64E-04

Table 7: Class average data for *Engineering Post-Assessment*

	Q3	Q4	Q5	Q6	Q7
Class Average Score	1.74	1.71	1.65	1.94	1.16

The results of Q2 and Q3 showed a significant increase in the students' knowledge of what an engineer does, but no increase in the knowledge of what a scientists does. There was an increase in students' agreement that they would consider engineering as a major in college but it was not statistically significant. Question 5 shows a very strong agreement in students feeling of the importance of engineering and the benefit to society that engineers provide. Questions 3-6 show that students were able to articulate how they performed each of the four engineering performance tasks from the NGSS within the unit. Question 7 shows that students were able to connect at least some of the science content learned in the physics course to the engineering projects.

The results of the *Energy Assessment* are shown in Table 8 (n=34). The assessment measured the students' improvement in the energy related HSCE's (Appendix J), as well as their knowledge of alternative energies, and their understanding of the current methods of energy use and the consequences of continued use. The results shaded dark grey showed no significant change based on statistical analysis and will be discussed in the discussion section.

Table 8: Class average data of *Energy Assessment*

	Q1	Q2	Q3	Q4	Q5
Pre-Test Average	0.088	0.971	0.853	0.265	0.500
Post-Test Average	1.656	1.594	1.625	1.313	1.625
P Value	6.00E-18	4.64E-05	4.41E-06	1.49E-07	2.32E-09
	Q6	**Q7**	**Q8**	**Q9**	**Q10**
Pre-Test Average	0.382	0.294	2.333	2.654	3.040
Post-Test Average	1.000	0.969	1.594	2.567	3.759
P Value	5.05E-05	2.43E-05	7.66E-03	2.91E-01	1.29E-02
	Q11	**Q12**	**Q13**	**Q14**	
Pre-Test Average	3.720	3.000	3.963	4.094	
Post-Test Average	4.375	3.219	4.531	4.906	
P Value	9.29E-04	2.04E-02	1.56E-03	6.35E-05	

The results show significant increase in all content knowledge questions (Q1-Q7). Question 8 shows students shift toward strong disagreement that fossil fuels are abundant and will not run out for a very long time. Questions 10-14 show a significant shift toward strong agreement that advances made by scientists and engineers can find affordable solutions to the dependence on fossil fuels, that work is essential to the advancement of mankind, and that we need to develop alternative energies now before it is too late.

The results of the *Electricity Assessment* are shown in Table 9 (n=34). The assessment measured students' growth of the electricity content knowledge required in the HSCE's (Appendix J). The results show significant increases in students' knowledge in all areas. The scores also show students are proficient in their understanding of voltage, current, resistance, Ohm's law, series and parallel circuit calculations and wiring diagrams. The average score of question 1d and question 6 shows students were not proficient in being able to identify Ohm's law as the relationship between voltage current and resistance, or their understanding the difference between electrical power and energy.

Table 9: Class average data of *Electricity Assessment*

	Q1a	Q1b	Q1c	Q1d	Q2	Q3a
Pre-Test Average	0.182	0.061	0.364	0.061	0.212	0.091
Post-Test Average	1.625	1.563	1.563	0.844	1.094	1.469
P Value	2.97E-13	9.83E-13	2.59E-08	3.81E-05	3.00E-06	1.66E-09
	Q3b	**Q6**	**Q7a**	**Q7b**	**Q7c**	**Q7d**
Pre-Test Average	0.091	0.030	0.061	0.000	0.000	0.000
Post-Test Average	1.406	0.581	1.774	1.839	1.548	1.290
P Value	7.61E-09	9.73E-05	3.86E-14	3.66E-18	5.34E-12	2.41E-11

Discussion

Discussion of Climate Change Results

The results of the *Climate Change Survey* (Appendix R) show that the developed unit was successful at teaching students the science behind climate change and causing a shift in their knowledge and opinions. Whether or not this will lead to a behavior change remains to be seen and would be impossible to measure for this research. The unit did include education focused on awareness, knowledge, skills, values, and opportunities for participation which McKeown and Hopkins (2010) argue will bring about in-depth learning and behavior change. Furthermore, a study by Paul C. Stern (2000) concluded that education which facilitates a moral approach that appeals to values, and education to change attitudes and provide information, if carefully executed, can change environmentally significant behavior. The results of the climate change survey show an increase in motivation for my students to look at information regarding climate change. Also the students agreed that they feel a moral duty to do something about climate change. Students also agreed that: a) carbon dioxide levels are being released by the burning of fossil fuels, b) greenhouse gases do prevent some of the sun's energy from radiating into space, c) climate change is happening and is likely influenced by humans, d) it should be a high priority for government officials, and e) decisions they make every day affect climate change. Responses to question 14 showed an increase in student motivation to look at information about climate change if they come across it. Additional responses to question 18 showed a strong increase in students' feeling educated enough to form their own opinion about climate change. Question 13 also showed that students feel global warming should be a high priority for the president and congress.

Responses to questions 8-11 on the *Climate Change Survey* (Appendix R) showed no statistical change. This result showed that the instruction in the unit did not cause students to disagree that a significant number of scientists have doubt about the evidence for climate change or that the climate changes are so slow that humans don't have to worry about it for hundreds of years or longer. Student also did not shift toward agreement that experts are agreed that climate change is a real problem. This result could be an indication of a deeply held belief by some students that the data are false and that climate change may be a hoax that the instruction could not overcome. It is also possible that student misread the problem or answered it too quickly. The results show a large shift toward disagreement that a significant number of scientists have doubts about the evidence, and a shift toward agreement that experts are agreed that it is a problem, but it wasn't statistically significant due to the large range of answers (1's and 5's). It is possible students did not make the distinction between our analysis of information from scientific sources, and the conflicting information from media sources. This could be addressed during instruction by making clear distinctions between them.

Some of the strongest evidence toward the effectiveness of the unit was not captured by the assessments. Multiple conversations occurred between the researcher and the students before and after school. Students began having a lot of questions and even did research on some new exciting things in alternative energies. There were students that chose alternative energy and climate related themes for an activism project for another class. Multiple students have written research papers about these topics in their English courses. A student returning from winter break told a story about a "huge argument" they had with their grandfather over the holidays about alternative energies. Although anecdotal in nature, this is perhaps the best indicator to the researcher that the unit was successful at motivating students to do something about the energy crisis and are thinking about the many facets of the problem outside of the classroom.

Discussion of Engineering Assessment Results

The results of the *Engineering Design Pre and post Assessments* (Appendix T) indicate that the unit was highly successful at teaching the engineering process and thoroughly covering the four engineering performance expectations from the NGSS. By implementing aspects of the Learning by Design ® model (Brophy, 2008), the students were also able to link scientific investigation and the knowledge gained to contribute to the engineering process. Questions 2 and 8 show students understanding of the engineering process and what an engineer does was significantly improved. The results for Question 2, "What does an engineer do?" show an average that is less than 1 on a 0-2 scale. The major reason for this was that students didn't write enough to meet the rubric's description of a 2 response. Many students tended to write as little as possible to answer the question.

The results of Question 10 show that the students almost unanimously strongly agree that well-trained engineers are important and beneficial to society. Question 9 shows that the unit did not significantly motivate students to consider engineering as a career or major in college. This result supports the research by Li, McCoach, Swaminathan, & Tang (2008) which found that students feel engineers are beneficial, but the program is difficult and the career is demanding. In retrospect, the engineering assessment should have been designed to capture student reasons why or why not to see if the conclusion the study Li, McCoach, Swaminathan, & Tang determined of college students holds true for high school students. Another possibility is that the experience motivated some to agree that they would consider engineering (the class average did increase slightly) and others to disagree. The unit may have helped some students realize the work of engineers is not suited for them, preventing them from pursuing engineering after high school. The experience may have helped reduce the low degree completion rates found by French, Immekus, & Oakes (2005). Upon analysis of the individual responses, most students moved one point either toward agreement or disagreement from pre to post assessment.

The students enjoyed the project-based engineering component of the class. The unit incorporated complex, authentic questions and carefully designed products and tasks as required by the Buck Institution's definition of PBL (Markham, Larmer, & Ravitz, 2003). The authenticity of the project raised student motivation in class. One student included on the assessment that, "The project made me feel like I was really part of the the class". Responses from other students showed that the students felt like real engineers and they were actually solving real problems and contributing to society with their work.

Barron et al. (1998) showed that students learn more with "enhanced conditions" that make the project authentic. The assigned engineering teams, student roles, and the structure of the class (engineering firm) worked very well to increase the authenticity of the project. Many students who typically were unmotivated and low-achieving in the standard classroom environment became key contributors of their groups. At the beginning of the project, some teams did not work well together. Many students felt they were only responsible for their job in the group and did not have to contribute to the other areas of the project. As student communication and delegation increased, the groups started working better as they understood how their role compliments the work of others in the group. These results also support findings in the literature about the benefits of peer-collaboration in PBL discussed in the introduction (Kampen, 2004) (Lattimer & Riordin, 2011).

PBL and engineering projects take a great deal of time to accomplish. At times during the unit the students felt very rushed to meet the deadlines for parts of the project. In the future, more time will be allowed to complete the projects. The unit blended instruction into the project so it is possible to start the project earlier in the unit. Students can begin the design process and complete the wind investigations, then there could be several days that interrupt the project to accomplish the other labs and activities of the unit. Setting a schedule of "work" days for the project mixed with the other activities would give students more time to think about and plan their design. This type of work could also be done outside of class. Spreading the project out over more days would allow the students more time to complete the project while using the same amount of class time for the unit.

Discussion of the Energy and Electricity Results

The results of *Energy Pre/Post Test* (Appendix S) and *Electricity Assessment* (Appendix U) indicate that the unit was very successful at teaching the concepts of electricity and energy. Interestingly, the results of question 10 showed students strongly agree that some forms of alternatives are comparable in cost to fossil fuels. However, the results of Question 9 showed no significant shift toward disagreement to the statement, "It is not feasible (too expensive) to stop using fossil fuels in the *near* future." These results seam to contradict one another. A possible reason for this is that the instruction helped students realize the overwhelming dependence our society has on fossil fuels and how difficult it is to shift that paradigm. This hypothesis is strengthened by the almost unanimous strong agreement by students that it is important to develop alternative energies now before it is too late (Question 14).

Final Analysis

In conclusion, this research indicated that it is possible to teach required content in a physics course while incorporating the engineering standards of the NGSS. This research also showed that instruction on the science of climate change and energy use/supply is not only possible to accomplish in a physics course, but provides a complex, worldwide problem to be solved through the engineering process and increases student motivation to participate in the solution.

Improvements

The unit totaled 22 class periods of instruction in the course and covered 2 units worth of material. This successfully met the two-week average per unit pace of the course. However, during the process, the students felt rushed and there was a high level of anxiety to finish. The quality of the final product suffered slightly from this time constraint. The engineering process modeled in this unit from NASA and the National Research Council (2012), takes a great deal of time to accomplish. The process required students to continuously test and improve their design. This work will produce a better product from the students, but also required more time than a science course can spare. There has to be limits. Spreading out a project over more days, as discussed previously, while supporting it with instructional days, would help to alleviate the time contraints. It is also possible to streamline the process used for some projects and not complete every step of the process.

During the windfarm design project, the student prepared a publically presented product as recommended by Larmer & Mergandoller (2010). Many groups did a fantastic job of presenting their proposal to the class. To continue the authenticity that was achieved by the other aspects of the project, it would be better to assemble a panel of adults (teachers, administrators, etc) to serve as a panel to hear the presentations. The adults could be given roles such as: energy corporation CEO, U.S. Senetor, Secretary of the U.S. Department of Energy, etc. I feel the quality of the presentations would improve if the students knew they were not just presenting to the class.

Another improvement to the engineering project would be set check-points that must be signed off by the teacher before continuing to the next step of the design process. Students struggled with steps 3-6 of the adopted design process (Appendix G). The students wanted to build what they thought would work, or that they thought was “cool”. They did not want to follow the design process to systematically choose the best option. Much of the student work on those steps of the design template was superficial, and in many cases biased to favor the design they wished to build rather than what their data indicated they should build.

The successes of the unit also lead to further questions about science education. Is it possible to teach my entire physics course using project-based engineering projects with various themes that would allow the exploration other physics content standards? Also, since PBL and the projects themselves encourage interdisciplinary learning, could science be taught in a more interdisciplinary way in the future? The adoption of the NGSS would allow for the content standards to be reorganized in a different way. The currrently required HSCE’s of Michigan fall into Biology, Chemistry and Physics courses. If the NGSS are adopted, courses could be developed that incorporate comprehensive project-based learning allowing a broader exploration of the sciences based on core concepts and the science and engineering practices.

Within the scope of an alternative energy theme, a course could have a more interdisciplinary science approach. The theme worked well for a physics course, but there are also energy related topics in biology, chemistry and Earth science as well. Biological standards could be taught by including an exploration of microbial hydrogen production, or natural gas production by anaeobic digestion as an alternative energy. Chemistry concepts could be covered by including an exploration of the synthesis of biodiesel, an exploration of the stored energy of hydrocarbons in fossil fuels, or an investigation of nuclear energy. Science educators would have an opportunity, if and when the NGSS are adopted, to offer new courses to provide the state required three credits of science that are more interdisciplinary in nature. The engineering standards can also be taught by adopting the methods of PBL and carefully designing projects that require exploration of a broad range of scientific content.

APPENDICIES

APPENDIX A:

Parent Consent Form

Parental Consent and Student Assent Form

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you to Physics I and invite you to participate in a research project which I will conduct as part of this course. My name is Mr. Bryan Tasior. I am your physics instructor and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researcher any questions you may have.

What is the purpose of this research? I have been working on effective ways to teach the topics of physics in a more meaningful way by incorporating more project-based learning and engineering practices. These practices align with the Next Generation Science Standards which are new benchmarks for science education. I plan to study the results of this teaching approach on student comprehension and retention of material. The results of this research will contribute to the understanding about the best way to teach about science topics. Completion of this research project will also help me earn my master's degree in Michigan State University's College of Natural Science.

What will students do? Students will participate in the usual instructional curriculum for Physics I, but with added emphasis on applying the knowledge to projects and engineering tasks. Students will complete all of the usual assignments, laboratory experiments and activities, class demonstrations, and assessments just as they would do for any other unit of instruction. Participation in this study will not increase or decrease the amount of work that students do. The techniques and activities used in class are part of the science curriculum of the State of Michigan and Stockbridge High School and are used in the classroom regardless of participation in the study. I will simply make copies of student's work for research purposes as part of the study. This project will take place in the second quarter in the Fall semester 2014. I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction and the skills and knowledge gained by students in my classroom. I will not know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, class demonstrations, and pretest/posttests. In fact, completing coursework will be very beneficial to students. I will store the consent forms (where you say "yes" or "no") in a locked cabinet that will not be opened until after I have assigned the grades for the semester. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all written work. Later I will analyze the written work as my data for my research for students who have agreed to participate in the study and whose parents/guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that will not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of students' original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board and MSU. The data will be stored on password-protected computers (during the study) and in locked file cabinets in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say "no." You may change your mind at any time and withdraw. If either the student or parent/guardian request to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

Who can you contact with questions and concerns? If you have questions or concerns about this study, please do not hesitate to contact:

Mr. Bryan Tasior
Stockbridge High School
416 N. Clinton St.
Stockbridge, MI 49285
tasiorb@panthernet.net
(517) 851-7770 ext.6118

Dr. Merle Heidemann
118 North Kedzie Lab
Michigan State University
East Lansing, MI 48824
heidma2@msu.edu
(517) 432-2152 ext. 107

If you have questions or concerns regarding your role as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if desired, MSU Human Research Protection Program at: **irb@msu.edu**

How should I submit this consent form? Please compete the attached form. Both the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. **Please return this form in a sealed envelope to the drop-box in Room 118 by the announced date.**

Parents/guardians should complete this following consent information:

I voluntarily agree to have ____
participate in this study.

(Student Name)

Please check the box that applies:

Data: (CHOOSE ONE)

__________ I give Bryan Tasior permission to use data generated from my child's work in this class for his thesis
project. All data shall remain confidential.

__________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be
graded in the same manner regardless of participation in this research.

Photography, audiotaping, or videotaping: (CHOOSE ONE)

__________ I give Bryan Tasior permission to use photos or videotapes of child in the class room doing
work related to this thesis project. I understand that my child will not be identified.

__________ I do not wish to have my child's images used at any time during this thesis project.

____

(Parent Signature) (Date)

____

(Student Signature) (Date)

Important: Please return this form in the sealed envelope to the drop-box in Room 118 by the announced date.

APPENDIX B:

Energy Transformation Lab

Energy Transformation Lab

Table 10: The 6 main forms of energy.

Type of Energy	Definition	Examples
Mechanical	Energy of motion	Sound, Waterfall, wind, moving objects.
Thermal	Energy due to the internal motion of particles. Change in temperature/phases.	Heat, rubbing hands together.
Chemical Potential	Energy that bonds atoms together. Energy stores in chemical bonds.	Gasoline, charcoal grill, energy in food.
Electro-magnetic	Electro-magnetic waves.	light, x-rays, radio waves. (all of the E.M. spectrum)
Electric (a form of E.M.)	Energy in the form of moving electric charges (current)	Current in wires, lightning
Nuclear	Energy in atomic nucleus.	Splitting an atom (fission, nuclear power plant) Fusing atoms into one atom (fusion, energy in stars)

At each station you will find common items. These items have certain forms of energy associated with them. These items transfer energy to different forms. At each station you will be observing the forms of energy and describing how energy is transferred to a different form. Try to think of every form of energy present and every energy transfer taking place. Write your responses including descriptions, not just a list of the energy transfer. Then draw an energy transformation diagram.

For example:

Item: The lights in the ceiling.

Describe forms of energy and energy transfer:
The lights on the ceiling are converting **Electric energy** in the form of electricity, to **Thermal energy** in the form of heat and **Electro-magnetic energy** in the form of light.

Energy Transformation diagram:

Electric Energy → Electromagnetic Energy → Thermal Energy

Station #1
Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Station #2
Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Station #3
Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Station #4
Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ___________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Station #5
Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Station #6
Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

Item: ________________________________
Describe forms of energy and energy transfer:

Energy Transformation diagram:

APPENDIX C:

Greenhouse in a Beaker Lab

Greenhouse in a Beaker Lab

Questions:

- What effect does adding carbon dioxide to the air have on the air's temperature during the day and night?
- Could having increasing levels of CO_2 in the atmosphere cause change the climate?

Hypotheses

- Write a hypothesis (prediction of result) of what will happen with CO_2 added to the air during the day (while sunlight is adding heat to the air).
  H1:____

  What results (data) would you expect to get to confirm your hypothesis?

- Write a hypothesis (prediction of result) of what will happen with CO_2 added to the air during the night (no sunlight is adding additional heat to the air, only heat from daytime cycle is present in air in the beaker).
  H2:____

  What results (data) would you expect to get to confirm your hypothesis?

Materials:

- 2 600 mL Beakers
- 1 250 mL Flask
- 1 Rubber stopper with hole
- 1 Vinyl tubing, 3/16” diameter, 60 cm long
- 1 Clip light
- 1 1000-1100 lumen bulb (equivalent to 75-watt incandescent)
- 1 Ruler
- 2 Probe thermometers
- Small piece of masking tape
- 4 Alka-Seltzer tablets
- Safety glasses
- 240 mL Water (room temperature)

Procedure:

Part 1—Day

1. Set up the light source 15 cm in front of the two beakers. The beakers should be receiving equal light.

2. Insert the tubing through the hole in the 250 mL flask. Place the other end of the hose near the bottom of one of the beakers. Secure the tubing inside the beaker with a small piece of masking tape.

3. Add 120 mL of water to the flask.

4. Turn on the clip light. Wait for the temperature in each beaker to stabilize. The temperatures in the beakers should be similar, but they do not have to be exactly the same.

5. Record the stable temperature of each beaker in the data table.

6. Break two Alka-Seltzer tablets in half and drop the pieces into the flask. Secure the rubber stopper.

7. Record the temperature of each beaker every 30 seconds for three minutes.

Part 2—Night

1. After you have data to model temperatures during the day, empty out your beakers and flask. Refill the flask with 120 mL water. Resecure the tubing inside one of the beakers.

2. Turn on the clip light. Wait for the temperature to stabilize. The temperatures in the beakers should be similar, but they do not have to be exactly the same.

3. Record the stable temperature of each beaker in the data table.

4. Break two more Alka-Seltzer tablets in half and drop the pieces into the flask. Secure the rubber stopper.

5. Turn off the light.

6. Record the temperature of each beaker every 30 seconds for three minutes.

Data:

Table 11: Simulated day-time data

	Beaker 1 (Without CO2)	**Beaker 2 (With CO2)**
Beginning Temperature		
30 s		
1 minute		
1 min 30 sec		
2 minutes		
2 min 30 sec		
3 min		

Table 12: Simulated night-time data

	Beaker 1 (Without CO2)	**Beaker 2 (With CO2)**
Beginning Temperature		
30 s		
1 minute		
1 min 30 sec		
2 minutes		
2 min 30 sec		
3 min		

Graph: Create a graph showing both day and night Data

Conclusion

Do you accept or reject your hypotheses? What were the results of your experiment? Use data to explain what happened.

Why do you think this happened?

How does this experiment relate to climate change on the Earth?

What were some aspects of the result that were surprising to you? (Unexpected results, surprising results, etc.)

What are new questions that have you have after completing this lab?

Are there any further experiments that could be done to study this further?

APPENDIX D:

Cosmos Episode Student Handouts

Directions: Answer the questions as you watch episode 12 of Cosmos: A Spacetime Odyssey

1. What planet is Neil deGrasse Tyson talking about when he says it used to be paradise?

2. How hot is the surface of Venus?

3. What are the clouds that block the Sun on Venus made of?

4. Which country landed a probe on Venus in 1982?

5. What is the difference in the way carbon is stored on Venus and on Earth?

6. What living thing created the White Cliffs of Dover?

7. What would Venus have needed in order to store carbon in the form of a mineral?

8. What on Earth primarily controls the amount of carbon dioxide in the air?

9. What did Charles David Keeling manage to do in 1958?

10. How can scientists read the “diary” of the Earth written in the snow?

11. What major event in history is the starting point of the exponential rise of carbon dioxide in the atmosphere?

12. How much carbon dioxide do volcanoes add to the atmosphere on Earth every year?

13. How did scientists conclude the extra carbon dioxide in the air contributing to climate change was not made from volcanoes, but instead comes from burning fossil fuels?

14. How much extra carbon dioxide are humans putting into the atmosphere every year by burning fossil fuels?

15. How much additional carbon dioxide has been spewed into the atmosphere since Carl Sagan first warned about doing so in the original “Cosmos” television series in 1980?

16. What do Neil deGrasse Tyson and his dog walking on the beach symbolize?

17. How are the polar ice caps an example of a positive feedback loop?

18. At what rate are the Arctic Ocean ice caps receding now?

19. How is the permafrost near the North Pole melting increasing carbon dioxide levels?

20. What are two ways we know that the Sun is not the cause of the current global warming trend?

21. What amazing invention did Augustin Mouchot first display in France in 1878?

22. Why was there no interest in Augustin Mouchot's invention after he won the gold medal at the fair?

23. Why did Frank Shuman's dream of irrigating the desert in Egypt never come to be?

24. How much of the wind's power would have to be tapped in order to run all of civilization?

25. The manned missions to the moon were a direct result of what period in the United States' history?

26. Who were the first group of people to stop wandering and begin civilization by using agriculture?

Directions: Answer the questions as you watch episode 9 of Cosmos: A Spacetime Odyssey.

1. On what day of the "cosmic calendar" is 350 million years ago?

2. Why could insects grow to be so much larger 350 million years ago than they can today?

3. How do insects take in oxygen?

4. How big was most vegetation on land before trees evolved?

5. What happened to the trees in the Carboniferous Period after they died?

6. Where were the eruptions centered during the mass extinction in the Permian Period?

7. What had the buried trees in the Carboniferous Period turned into and why was this bad during the time of the eruptions in the Permian Period?

8. What is another name for the Permian mass extinction event?

9. New England was a neighbor to which geographical area 220 million years ago?

10. The lakes that broke apart the great supercontinent turned into what eventually?

11. What did Abraham Ortelius say ripped America away from Europe and Africa?

12. How did most scientists in the early 1900s explain that certain dinosaur fossils were found in both Africa and South America?

13. How did Alfred Wegener explain why there were the same mountains on opposite sides of the Atlantic Ocean?

14. What happened to Alfred Wegener the day after his 50th birthday?

15. What did Marie Tharp discover in the middle of the Atlantic Ocean after drawing a map of the ocean floor?

16. How much of the Earth lies beneath 1000 feet of water?

17. What is the longest submarine mountain range in the world?

18. What is the name of the deepest canyon on Earth and how deep is it?

19. How do species get light at the bottom of the ocean?

20. What is the process bacteria use in the trenches in order to make food when sunlight doesn’t reach that far?

21. What created the Hawaiian Islands millions of years ago?

22. What is the core of the Earth made of?

23. What two things keeps the mantle a molten liquid?

24. How long were dinosaurs on the Earth?

25. What did Neil deGrasse Tyson say the temperature of the Mediterranean basin was hot enough to do when it was still a desert?

26. How did tectonic forces bring North and South America together?

27. What two adaptations did early human ancestors develop in order to swing from trees and to travel short distances?

28. Why were human ancestors forced to adapt to living and traveling on the ground?

29. What caused the Earth to tilt on in axis?

30. How did the human ancestors get to North America?

31. How long is the current intermission in the Ice Age projected to last?

APPENDIX E:

Frontiers in Science Presentations

Frontiers in Science Presentations

Information and data obtained at these sessions were used in the classroom during the Energy Unit reported in this study.

"Celluosic Biofuels"

Presented by Bruce Dale: October 20, 2012

"Why Do We Not Get our Energy from the Sun and How Can we change that"

Presented by Richard Lunt: December 15, 2012

"The Future of Power"

Presented by Wolfgang Bauer: December 7, 2013

APPENDIX F:

Climate Change Articles Homework

Climate Change Articles Homework

Find 4 articles online about global climate change. You may need to do a little research about the source to answer the questions.

1. **Title: ____**

Source: (name of publication, organization, etc.): ___________________________________

Major arguments for or against Climate Change:

What bias could be present in the article (intended audience of article, or motives of the author)? Explain.

What are your thoughts about the scientific accuracy of the article?

2. **Title: ____**

Source: (name of publication, organization, etc.): ___________________________________

Major arguments for or against Climate Change:

What bias could be present in the article (intended audience of article, or motives of the author)? Explain.

What are your thoughts about the scientific accuracy of the article?

3. **Title:** ____

Source: (name of publication, organization, etc.): ___________________________________

Major arguments for or against Climate Change:

What bias could be present in the article (intended audience of article, or motives of the author)? Explain.

What are your thoughts about the scientific accuracy of the article?

4. **Title:** ____

Source: (name of publication, organization, _______________________________________

Major arguments for or against Climate Change:

What bias could be present in the article (intended audience of article, or motives of the author)? Explain.

What are your thoughts about the scientific accuracy of the article?

APPENDIX G:

Engineering Design Template

Engineering Design

Design → Evaluate → Refine

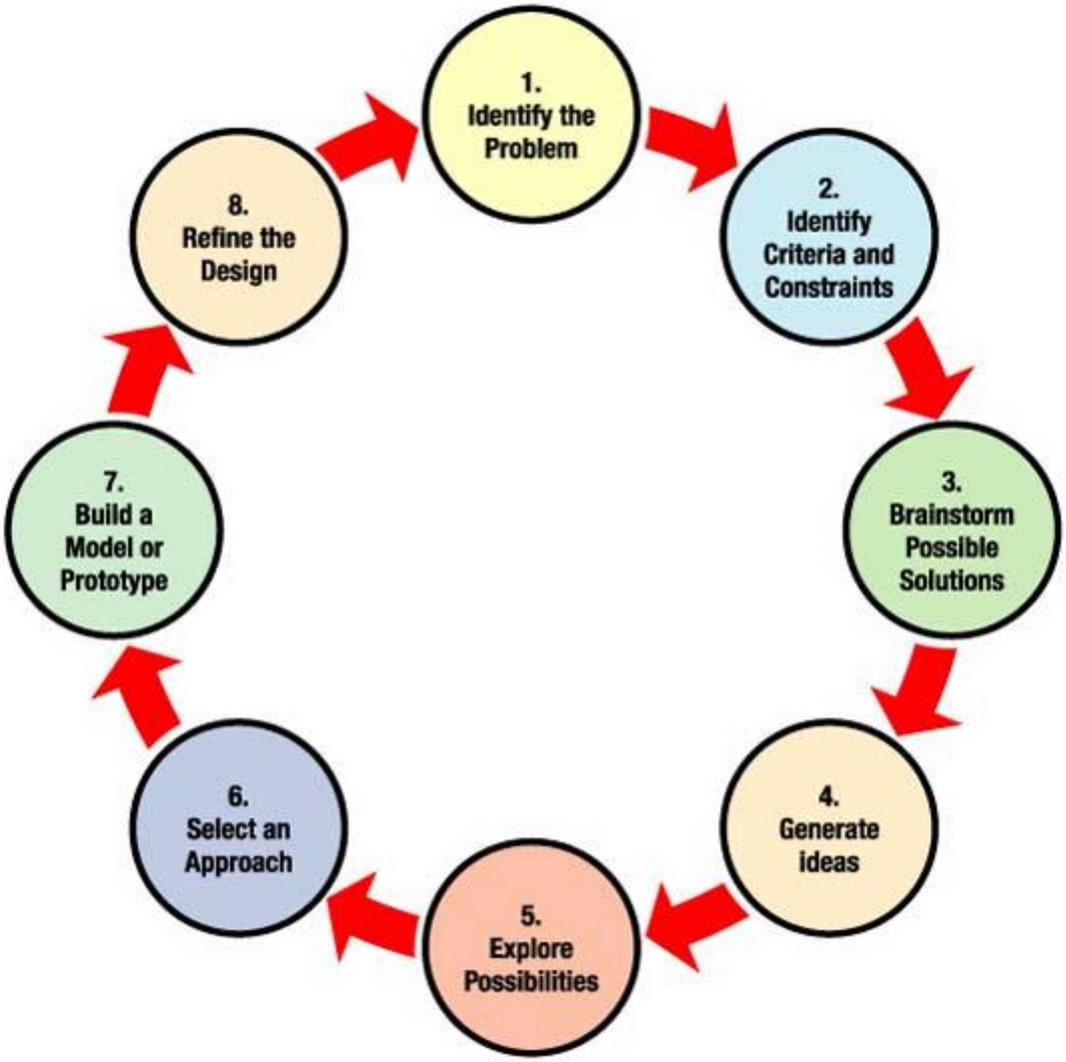

Figure 4: NASA Engineering Design Template. http://www.nasa.gov/audience/foreducators/plantgrowth/reference/Eng_Design_5-12.html#.U6l_efm-2Fw

STEP 1: Identify the Problem - Students should state the challenge problem in their own words. Example: How can I design a __________ that will __________?

- ✓ **Who is the client?**
- ✓ **What is the project?**
- ✓ **Who are the designers?**
- ✓ **What is the problem statement?**
- ✓ **What is the design statement?**

STEP 2: Identify Criteria and Constraints - Students should specify the design requirements (criteria).

- ✓ **What are the constraints? (Materials, time, size, assembly, safety, cost, performance, etc.)**

STEP 3A: **Gather Information** - Research any possible information that might be needed for project.

STEP 3B: Ideation/Brainstorm Possible Solutions - Each student in the group should formulate/sketch his or her own ideas as the group discusses ways to solve the problem. Labels and arrows should be included to identify parts and how they might move. These drawings should be quick and brief.

- Defer Judgment
- Go for Volume
- Build on the ideas of others, encourage wild ideas
- One conversation at a time, stay on topic

STEP 4: Generate Ideas - In this step, each student/group should develop two or three ideas more thoroughly.

- ✓ **Incorporate the best ideas into 3-4 different sketches of the final product.**
- Sketches can include writing and labels identifying important aspects
- Think about constraints

STEP 5: Explore Possibilities - The developed ideas should be shared and discussed among the team members.

- ✓ **Record pros and cons of each design. Can be done on sketches.**

STEP 6: Select an Approach - Students should work in teams and identify the design that appears to solve the problem the best. Students should have a statement that describes why they chose the solution. This should include some reference to the criteria and constraints identified above.

- ✓ **Create a decision matrix based on criteria and constraints**
- Prioritize constraints, which ones are more important?
- Try to eliminate bias. Pursue the best choice, not the one you WANT to build for any other reasons (it's cool etc.)

	COST	SIZE	AESTHETICS	TEMPERATURE	SAFETY	TOTAL
Sketch # 1	2	3	5	4	1	15
Sketch # 2	5	4	2	3	5	19
Sketch # 3	3	2	4	4	4	17

Scale: 1-5 1 = worst 5 = best

Figure 5: Example decision matrix. Criteria will vary based on the project.

STEP 7: Build a Model or Prototype - Students will construct a full-size or scale model based on their drawings.

- Try out the prototype, or have peers critique.
- ✓ **Document performance of prototype(s). Could be data and/or descriptive.**
- ✓ **Identify what changes could be made to improve performance**

STEP 8: Refine the Design - Students will examine and evaluate their prototypes or designs based on the criteria and constraints. Groups may enlist students from other groups to review the solution and help identify changes that need to be made. Based on criteria and constraints, teams must identify any problems and proposed solutions.

- **Test, Rebuild, Refine**
- Incorporate new ideas into a new design.
- The design process lasts as long as the product is on the market.
- ✓ **Document performance of new prototype(s). Could be data or descriptive.**
- ✓ **Document whether or not the changes were successful and propose any addition modifications that would improve your design.**

Final Product: The final product may vary depending on the nature of the project

Documentation of the engineering process is important and should be done as students work through the process. **All Required aspects for the documentation are listed in bold with a ✓ to indicate they are required in the write-up.** This handout can be used as a template to write up the engineering process and will be graded on required elements.

Table 13: Engineering Design Template Rubric

CATEGORY	2	1	0
Step 1: Identify the problem	Problem is clearly defined with all required items from the checklist	Problem is reasonably defined with most of the required items from the checklist.	Problem is poorly defined with inadequate inclusion of required items from the checklist
Step 2: Identify criteria and constraints	Multiple criteria are well defined and are relevant to the project. All relevant criteria are present.	Criteria are present with relevance to project. Some major criteria may be missing.	Criteria are inadequate, missing or not relevant.
Step 3A: Research	Research is included that affect the major aspects of design. Research provides background information necessary to be successful.	Research is present but does not directly affect the design. Information is only vaguely connected to design performance.	Research is inadequate or missing.

Table 13: (con't)

Step 3B: Brainstorm	Multiple ideas are explored in detail.	Few ideas are explored. OR Ideas are not well thought out and presented.	Insufficient exploration of design ideas. Few or poorly presented ideas.
Step 4: Generate ideas	Top choices chosen are reasonable and probable to be best choices. Choices are fully developed including labeled diagrams. Professional appearance.	Incomplete or poorly labeled diagrams, top choices are not all explored fully or too much emphasis on one. Acceptable appearance.	Only one choice is explored ignoring other options. Missing diagrams or inadequate appearance.
Step 5: Explore Possibilities	Professional appearance and fully developed list of pros and cons that are relevant and meaningful.	Acceptable appearance OR pros and cons are present but only trivial.	Incomplete
Step 6: Select and Approach	Neatly presented decision matrix with well-chosen criteria and constraints weighted properly leading to the best choice.	Decision matrix is present. Criteria may be only partially relevant and values used are arbitrarily chosen and do not make the matrix as useful to choose.	Matrix may be absent are poorly completed making it unusable to choose best option.
Step 7: Build a model or prototype	Well-constructed prototype. Tested with valuable and accurate measurements. Proper mathematical models (calculations) correctly used accurately document performance.	Complete prototype. Tested with measurements. Mathematical models (calculations) used but may have errors or not measure most important data.	Poor or incomplete prototype. Major flaws in measurement or mathematical models.

Table 13: (con't)

Step 8: Refine the design	First prototype is evaluated and a meaningful refinement is proposed to increase performance. Tested properly (as in last section)	First prototype is evaluated and a refinement is proposed to increase performance but may be just a guess. OR Tested improperly (as in last section)	Refinements not made.
Final: Communicate results	Presentation of project is complete, professional, and meets all additional requirements given for the presentation.	Presentation of project is complete, and meets most requirements given.	Presentation of project is incomplete, or meets few of the requirements given.

APPENDIX H:

Exploring Wind Design Project

Exploring Wind Design Project

Introduction: Michigan Energy Corporation is looking for alternatives to their coal-fired power plants to produce electricity. Growing energy needs of residential, commercial and industrial consumers as well as growing concerns over human activity (burning fossil fuels) causing changes in climate and environmental quality have led to the energy company needing to find low emission, renewable resources. The cost of fossil fuels is increasing as the supply becomes more limited and the demand increases. The need for renewable resources that are cost efficient (comparable to costs associated with fossil fuels) has become vital to avoid falling into energy poverty that would significantly decrease our standard of living.

One of the renewable resources they are investigating for use is wind power. They have contacted your engineering firm and asked you to design wind turbine blades that produce the most power. Your team has been given ___________ days to come up with the most successful design to be presented to them. Your design must be safe to operate, be made from inexpensive and readily available materials, be easy to produce in mass quantities, be able to fit on a generator tower that requires your blades to be no longer than 40cm (measured from center of hub to tip of blade), in order to have clearance on the tower, produce the highest voltage reading possible and have the highest efficiency rating. Your blades can have any design and materials choices you wish within the given constraints. Several other engineering firms are concurrently working on this project. The winning design will be selected to design wind farms containing your turbines. (Will you get the job?)

(Design Project Team Name)

Client: ____
_

Project:____
____
____
____

Designers: ___________________________ ___________________________

___________________________ ___________________________

___________________________ ___________________________

Problem Statement:

____
____
____
____
____
____
____
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____
____
____
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____
____
____
____

Design Statement:

2. **Constraints:**

3. **Ideation/Brainstorming:**

   3A: Research. Complete the Wind Investigations before continuing.

   Briefly summarize the important design aspects of your blade

   3B: Brainstorm

Additional sheets may be attached if necessary

4 &5. Top 3-4 Design Options (labeled sketches) with Pro's and Con's listed

Additional sheets may be attached if necessary

6. **Select an Approach:** Create and complete a decision matrix below

7. **Build Prototype and Test**

Read page 18 of student guide. SHOW ALL WORK including equations when necessary.

Calculate power of the wind at the .5 m distance on low and high

Low speed voltage: ____________________

Low speed voltage with resistor connected: ______________________

Low speed current with resistor connected: ______________________

Low speed electrical power produced by turbine:

High speed voltage: ___________________

High speed voltage with resistor connected: _____________________

High speed current with resistor connected: _____________________

High speed electrical power produced by turbine:

Efficiency of turbine at high wind speed:

Describe any performance aspects not captured by the data (blades bent, broken, etc.)

Describe changes you can make to refine the design and why those are necessary.

8. Refine the Design

Low speed voltage: ____________________

Low speed voltage with resistor connected: ______________________

Low speed current with resistor connected: ______________________

Low speed electrical power produced by turbine:

High speed voltage: ___________________

High speed voltage with resistor connected: _____________________

High speed current with resistor connected: _____________________

High speed electrical power produced by turbine:

Describe any performance aspects not captured by the data (blades bent, broken, etc.)

Describe if your changes made to the new prototype were successful. Are there any future changes that could be made to further improve performance?

Model the Performance of a single turbine

Include the following calculations in your presentation

Energy produced by best model blades in 1 day (Joules):

Energy produced by best model blades in 1 day (kWh):

Energy produced by best model blades in 1 year (Joules):

Energy produced by best model blades in 1 year (kWh):

Scaling your model: How powerful would your turbine be full-scale?

Area: The swept area of the full-scale blades will be much larger. The blades will be 50m long from center to the end of the blade. The area is directly proportional to the power so an increase in the area will cause the same increase in power production.

Area of model blades:__________________ Area of real blades:_______________________

Real blades/model blades = **______________________** **Area multiplier: ________x**

Gears: The full scale blades will include a gear box with a 300:1 ratio. This means your generator will spin 300 times for every 1 time the blades turn. **Gearbox multiplier: _300__x**

Efficiency: The full size generator is 35x more efficient at producing electricity from mechanical work.

Efficiency multiplier: ___35 x

Power of model turbine (high speed): _____________________

P = _____________ x _______________ x____300______ x ______35___ = _______________ W
Model power X Area multiplier X Gearbox multiplier X Efficiency multiplier = Full-Scale Power

Full scale power in MW (megawatts): ______________________MW

Energy produced by real blades in 1 day (Joules):

Energy produced by real blades in 1 day (kWh):

Energy produced by real blades in 1 year (Joules):

Energy produced by real blades in 1 year (kWh):

The average US household uses 10,837 kwh of electricity per year. How many homes could one of your blades supply power to?

APPENDIX I:

Next Generation Science Standards Engineering Performance Standards

NGSS Engineering Performance Standards:
Accessed at http://www.nextgenscience.org/msets1-engineering-design

Students who demonstrate understanding can:

MS-ETS1-1.	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
MS-ETS1-2.	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
MS-ETS1-3.	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
MS-ETS1-4.	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

APPENDIX J

Michigan High School Content Expectations Covered in Energy Unit

Michigan Physics HSCE's Covered in Energy Unit

Available From the Michigan Department of Education

https://www.michigan.gov/documents/Physics_HSCE__168208_7.pdf

P1.1 Scientific Inquiry: Science is a way of understanding nature. Scientific research may begin by generating new scientific questions that can be answered through replicable scientific investigations that are logically developed and conducted systematically. Scientific conclusions and explanations result from careful analysis of empirical evidence and the use of logical reasoning. Some questions in science are addressed through indirect rather than direct observation, evaluating the consistency of new evidence with results predicted by models of natural processes. Results from investigations are communicated in reports that are scrutinized through a peer review process.

P1.1A Generate new questions that can be investigated in the laboratory or field.

P1.1B Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.

P1.1C Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity–length, volume, weight, time interval, temperature–with the appropriate level of precision).

P1.1D Identify patterns in data and relate them to theoretical models.

P1.1E Describe a reason for a given conclusion using evidence from an investigation.

P1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

P1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

P1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

P1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

P1.2 Scientific Reflection and Social Implications: The integrity of the scientific process depends on scientists and citizens understanding and respecting the "Nature of Science." Openness to new ideas, skepticism, and honesty are attributes required for good scientific practice. Scientists must use logical reasoning during investigation design, analysis, conclusion, and communication. Science can produce critical insights on societal problems from a personal and local scale to a global scale. Science both aids in the development of technology and provides tools for assessing the costs, risks, and benefits of technological systems. Scientific conclusions and arguments play a role in personal choice and public policy decisions. New technology and scientific discoveries have had a major influence in shaping human history. Science and technology continue to offer diverse and significant career opportunities.

P1.2A Critique whether or not specific questions can be answered through scientific investigations.

P1.2B Identify and critique arguments about personal or societal issues based on scientific evidence

P1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

P1.2D Evaluate scientific explanations in a peer review process or discussion format.

P1.2E Evaluate the future career and occupational prospects of science fields.

P1.2f Critique solutions to problems, given criteria and scientific constraints.

P1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

P1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

P1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

P1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

P1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

Standard P4: Forms of Energy and Energy Transformations: Energy is a useful conceptual system for explaining how the universe works and accounting for changes in matter. Energy is not a “thing.” Students develop several energy-related ideas: First, they keep track of energy during transfers and transformations, and account for changes using energy conservation. Second, they identify places where energy is apparently lost during a transformation process, but is actually spread around to the environment as thermal energy and therefore not easily recoverable. Third, they identify the means of energy transfers: collisions between particles, or waves.

P4.1 Energy Transfer Moving objects and waves transfer energy from one location to another. They also transfer energy to objects during interactions (e.g., sunlight transfers energy to the ground when it warms the ground; sunlight also transfers energy from the Sun to the Earth).

P4.1A Account for and represent energy into and out of systems using energy transfer diagrams.

P4.1B Explain instances of energy transfer by waves and objects in everyday activities (e.g., why the ground gets warm during the day, how you hear a distant sound, why it hurts when you are hit by a baseball).

P4.2 Energy Transformation Energy is often transformed from one form to another. The amount of energy before a transformation is equal to the amount of energy after the transformation. In most energy transformations, some energy is converted to thermal energy.

P4.2A Account for and represent energy transfer and transformation in complex processes (interactions).

P4.2B Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion).

P4.2C Explain how energy is conserved in common systems (e.g., light incident on a transparent material, light incident on a leaf, mechanical energy in a collision).

P4.2D Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle.

P4.2e Explain the energy transformation as an object (e.g., skydiver) falls at a steady velocity.

P4.2f Identify and label the energy inputs, transformations, and outputs using qualitative or quantitative representations in simple technological systems (e.g., toaster, motor, hair dryer) to show energy conservation

P4.10 Current Electricity: Circuits Current electricity is described as movement of charges. It is a particularly useful form of energy because it can be easily transferred from place to place and readily transformed by various devices into other forms of energy (e.g., light, heat, sound, and motion). Electrical current (amperage) in a circuit is determined by the potential difference (voltage) of the power source and the resistance of the loads in the circuit.

P4.10A Describe the energy transformations when electrical energy is produced and transferred to homes and businesses.

P4.10B Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation.

P4.10C Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits, and short circuits and explain the reasons for the classification.

P4.10D Discriminate between voltage, resistance, and current as they apply to an electric circuit. P4.10x Current Electricity — Ohm's Law, Work, and Power In circuits, the relationship between electric current, I, electric potential difference, V, and resistance, R, is quantified by $V = I R$ (Ohm's Law). Work is the amount of energy transferred during an interaction. In electrical systems, work is done when charges are moved through the circuit. Electric power is the amount of work done by an electric current in a unit of time, which can be calculated using $P = I V$.

P4.10e Explain energy transfer in a circuit, using an electrical charge model.

P4.10f Calculate the amount of work done when a charge moves through a potential difference, V.

P4.10g Compare the currents, voltages, and power in parallel and series circuits.

P4.10h Explain how circuit breakers and fuses protect household appliances.

P4.10i Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players).

P4.10j Explain the difference between electric power and electric energy as used in bills from an electric company.

APPENDIX K:

Wind Turbine Blade Investigations

1. Exploring Blade Pitch

Question: How does the blade's pitch (angle) affect the electrical output?

Hypothesis/Prediction: (if…then…because)

Independent Variable (manipulated):

Dependent Variable (responding):

Controlled Variables: ____

Materials:

- Poster board
- Dowels
- Scissors
- Masking tape
- Hub
- Protractor
- Turbine testing station (turbine tower,
- multimeter, fan)
- *Benchmark Blade Template*

Procedure:
1. Using the benchmark blade template, make three blades out of poster board. Space them evenly around the hub.
2. Slip the protractor around the dowel. Set the blades to a pitch of 90 degrees.
3. Put your hub on the turbine tower and observe the results. Record the data.
4. Set your blades to a new pitch and test again. This is your second trial. Record your data.
5. Repeat Step 4 at least 4 more times to try to find the optimum pitch for the greatest electrical output.

Table 14: Blade Pitch Data

Pitch	Voltage
90°	

Graph:

Conclusion: Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain which blade pitch you will proceed with for your next investigations and why.
Note: The pitch you decided was optimal for the greatest electrical output today will now be a controlled variable. You will continue to use this pitch in the next investigations.

2. Exploring Number of Blades

Question: How do the number of blades on a turbine affect the electrical output?

Hypothesis/Prediction: (if…then…because)

Independent Variable (manipulated):

Dependent Variable (responding):

Controlled Variables: ____

Materials:

- Poster board
- Dowels
- Scissors
- Masking tape
- Hub
- Protractor
- Turbine testing station (turbine tower,
- multimeter, fan)
- *Benchmark Blade Template*

Procedure:

1. Decide how many blades you will be testing and make enough blades for the maximum number you will be testing.
2. In the data table, put down the greatest electrical output from the blade pitch investigation of the three benchmark blades.
3. Put the number of blades you want to test into the hub. They should have the same pitch as in the previous investigation.
4. Put your hub onto the turbine tower and test the number of blades. Record the results as trial 1.
5. Repeat steps 3-4 at least two more times to try to find the optimum number of blades for the greatest electrical output.

Table 15: Number of Blades Data

# of blades	**Voltage**
2	
3	
4	

Graph:

Conclusion: Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how many blades are ideal for a turbine and why.

Note: The # of blades you decided was optimal for the greatest electrical output today will now be a controlled variable. You will continue to use this # in the next investigations.

3. Exploring Surface Area

Question: How does the surface area of the blades affect the electrical output?

Hypothesis/Prediction: (if…then…because)

Independent Variable (manipulated):

Dependent Variable (responding):

Controlled Variables: ____

Materials:

- Poster board
- Dowels
- Scissors
- Masking tape
- Hub
- Protractor
- Turbine testing station (turbine tower,
- multimeter, fan)
- *Benchmark Blade Template*

Procedure:

1. Calculate the surface area of the benchmark blade. In the data table, record the surface area and the greatest electrical output from your previous investigation of the benchmark blades. The formula for finding the area of a trapezoid is one half the sum of both bases, multiplied by the height or, $A = ½ (b_1 + b_2) h$.
2. Keep the same shape as the benchmark blade, but change the length and/or width. This will change the surface area of the blade.
3. Make your new blades. You should have the same number of blades that you found had the best results in your previous investigation.
4. Find the surface area for each of your new blades.
5. Put your blades into the hub and onto the turbine tower. Test for electrical output and record data.
6. Repeat steps 2-5 at least two more times to try to find the optimum surface area for the greatest electrical output.

Table 16: Surface Area Data

Surface Area	**Voltage**

Graph:

Conclusion: Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how surface area affects performance.
Note: The surface area you decided was optimal for the greatest electrical output today will now be a controlled variable. You will continue to use this in the next investigations.

4. Exploring Mass

Question: How does the mass of the blades on a turbine affect the electrical output?

Hypothesis/Prediction: (if…then…because)

Independent Variable (manipulated):

Dependent Variable (responding):

Controlled Variables:

Materials:

- Optimum blades from previous investigation
- Pennies (or other mass)
- Masking tape
- Turbine testing station
- Protractor

Procedure:
1. In the data table, record your results from your previous investigation on the row with zero grams.
2. Tape one penny near the base of each blade, an equal distance from the center of the hub.
3. Test and record the electrical output. Repeat, adding another penny. If adding mass increases the output, add more pennies one at a time until you determine the ideal mass for the greatest electrical output.
4. Distribute the pennies on the blades at different distances from the hub until you determine the optimal distribution of mass for the greatest electrical output.

Table 17: Blade Mass Data

Additional Mass	**Voltage**
0 g	

Graph:

Conclusion: Do you accept or reject your hypothesis? Use results from your data table to support your reasoning and explain how mass and distribution of it on the blades affects performance. (to address distribution of mass, is it best to have mass distributed evenly, close to center, closer to outside of blades)

Blade Optimization Research

Are there other factors that affect blade performance we have not investigated? Read pages 14-17 in the Exploring Wind Energy Student Guide and label the diagram below with other factors you should consider when design optimum blades. <u>Define major science concepts used (Bernoulli's principle, Torque, etc.)</u>

Drag:

Lift:

Torque:

Aerodynamics

Use the space below to put any other useful information from the reading and any information you find online about how to design and build optimum blades.

Calculating Power from Wind
Read pages: 6, 12-13, 18-19 in the Student Guide

Question
How do you calculate wind power?

Materials **Fan # ______________**

- Fan
- Wind gauge
- Turbine with benchmark blades
- Meter stick

Formula
Power = ½ $\rho A v^3$
Where ρ = air density (ρ = 1.2 kg/m^3 at standard ambient temperature and pressure); A = swept area of fan ($A = \pi r^2$; π = 3.1416); v = velocity
Watts = ½ (kg/m^3) x (m^2) x $(m/s)^3$

Procedure
1. Measure the radius of the turbine blade assembly and calculate the area swept by the blades. **($A = \pi r^2$)**

2. Use the wind gauge to measure the wind velocity at a distance of 1 meter from the fan on low and high speeds in both miles per hour and meters per second (m/s).
(1 mile = 1609.344 meters)
Wind Velocity at Low Speed - 1 meter: ____________ mph = ____________m/s
Wind Velocity at High Speed - 1 meter: ____________ mph = ____________m/s

3. Use the formula above to calculate the power of the wind in watts at both fan speeds. (Show Work)

Wind Power at Low Speed - 1 meter: ____________W
Wind Power at High Speed - 1 meter: ____________W

4. Vary the distance from the fan and calculate the power on low and high speeds.

Wind Power at ___________m (distance A) on Low Speed: ___________W
Wind Power at ___________m (distance A) on High Speed: ___________W
Wind Power at ___________m (distance B) on Low Speed: ___________W
Wind Power at ___________m (distance B) on High Speed: ___________W

Conclusion
1. Compare the power at different distances from the fan and on different fan speeds.

2. Explain the relationships between the different variables and the power produced.

APPENDIX L:

Energy and Power Practice

Energy and Power Practice

Part 1: (Adapted from electicity lesson by Nicole McMahon found from Michigan Technological University www.geo.mtu.edu/rs4hazards/Project%20resources/Electricity.docx)

Suppose your toaster consumes 500 Watts of electricity. You are going to toast 24 pieces of bread (one at a time), and each piece of toast takes 5 minutes. How much electricity are you consuming to cook the toast? If each kWh (kilowatt-hour) of electricity costs $0.10, how much does it cost to toast the bread?

To calculate how much electricity you are using, you have to calculate the kWh (kilowatt-hour), which is the watts of electricity multiplied by the number of hours the appliance is in use.

_____ pieces of toast x _____ minutes per piece = _____ minutes = _____ hour(s)

_______ watts x ______ hours = _______ Wh = _______ kWh

To calculate the cost, you have to multiply the amount of electricity by the unit price.

_______ kWh x ______ unit price = $________

Suppose your microwave consumes 1000 Watts of electricity. You are going to cook 6 TV Dinners (one at a time) that each take 5 minutes. How much electricity are you consuming to cook the dinners? If each kWh (kilowatt-hour) of electricity costs $0.10, how much does it cost to cook the dinners?

To calculate how much electricity you are using, you have to calculate the kWh (kilowatt-hour), which is the watts of electricity multiplied by the number of hours the appliance is in use.

_____ dinners x _____ minutes per dinner = _____ minutes = _____ hour(s)

_______ watts x ______ hours = _______ Wh = _______ kWh

To calculate the cost, you have to multiply the amount of electricity by the unit price.

_______ kWh x ______ unit price = $________

Suppose your television consumes 5000 Watts of electricity. You are going to watch four episodes of SpongeBob SquarePants, each 30 minutes long. How much electricity are you consuming to watch the shows? If each kWh (kilowatt-hour) of electricity costs $0.10, how much does it cost to watch the shows?

To calculate how much electricity you are using, you have to calculate the kWh (kilowatt-hour), which is the watts of electricity multiplied by the number of hours the appliance is in use.

_____ episodes x _____ minutes per episode = _____ minutes = _____ hour(s)

_______ watts x ______ hours = _______ Wh = _______ kWh

To calculate the cost, you have to multiply the amount of electricity by the unit price.

_______ kWh x ______ unit price = $________

Suppose your oven consumes 3000 Watts of electricity. You are going to cook 6 pies (one at a time), each for 30 minutes. How much electricity are you consuming to cook the dinners? If each kWh (kilowatt-hour) of electricity costs $0.10, how much does it cost to cook the dinners?

To calculate how much electricity you are using, you have to calculate the kWh (kilowatt-hour), which is the watts of electricity multiplied by the number of hours the appliance is in use.

_____ pies x _____ minutes per pie = _____ minutes = _____ hour(s)

_______ watts x ______ hours = _______ Wh = _______ kWh

To calculate the cost, you have to multiply the amount of electricity by the unit price.

_______ kWh x ______ unit price = $________

Part 2

Students complete *Home Energy Use practice Sheet* available by Consumers Energy at

www.ConsumersEnergy.com/kids

APPENDIX M:

Communicate Results Portion of Wind Power Project

Communicate Results

Prepare a presentation to Michigan Energy Corporation (PowerPoint or other method) of your engineering design process and final product. The chosen firm will be selected to further the process and design and construct your wind farms in Michigan for power. The company also wants you to detail a plan to further your design by building wind farms in Michigan using your turbines.

The federal government is willing to subsidize (no interest charged) a 9.3 billion dollar loan to the energy company with the best plan to implement wind power in their state. This figure is a large sum of money but represents only 10% of the profits (not revenue) from the top five oil companies from last year! Your firm was selected to design wind farms in Michigan using your turbines. The engineering team with the plan that has the largest impact on Energy production in Michigan will be awarded the opportunity to design and build wind farms in Michigan using the 9.3 billion dollars. Your team must use the provided computer models to develop the best solution. Several interested, and powerful, groups are keeping a close eye on the project. Some groups will be opposed to certain uses and placements of farms and others may support them. Your team must consider constraints involved in the project that include cost, safety, societal needs and wants, environmental impacts, and address them in your presentation.

Required elements of presentation:

- Presentation of design process of turbine blades
- Mathematical modeling of large scale performance of turbine
- Design wind farms in specific locations of Michigan using computer models. (see below)
  - Include calculations from wind farm calculator in presentation.
- Address constraints on the project from the "Siting a Wind Farm" activity.
- Present general pros and cons of implementation of the design and wind power in general. Convince your audience!

Using computer models to design wind farms using your turbines

http://www.eia.gov/state/?sid=MI <-Interactive map

It will help if you clear all layers and add the ones you are interested in. Wind data for an area can be found by clicking on the area and looking up the wind class data. Be sure to check where wind power is already in use, an area may not be available to you.

Use the wind farm calculator spreadsheet to model the cost and performance of your wind farms based on location (wind speed). For the spreadsheet, use provided resources to look up and fill in the yellow cells. You may use any combination of turbine types, number, location etc. as long as you work within the constraints (cost, social etc.). You my build multiple farms with different #'s of turbines in different areas of the state as long as you stay within constraints.

Resources needed:

http://rredc.nrel.gov/wind/pubs/atlas/tables/1-1T.html ← Wind class data

http://www.eia.gov/electricity/data/state/ ← Net Generation, Fossil Fuel Consumption, and Avg Price by State

http://www.eia.gov/forecasts/capitalcost/ ← Cost of construction and operation/maintenance (Table 1)

Feel free to save the spreadsheet(s) to your drive with your figures to include in your presentation.

Siting a Wind Farm (adapted from NEED organization Exploring Wind Power Student Guide)

What additional constraints (social needs/wants, safety, reliability, cultural, environmental impacts) will your team use to evaluate the location and construction of your wind farm?

Use the various perspectives below to research your constraints. Some questions and concerns are listed below each group. Be sure to address a sufficient number of concerns. Some concerns are common among groups, be sure to make those a priority to address. A graphic organizer is provided to help you document your findings. Your group should divide the work among your members. Additional copies of the graphic organizer will be made available.

Governmental Agency Representative–BLM

The Bureau of Land Management is an agency in the federal government that is responsible for managing and conserving the resources that are on public land. The BLM has a policy of encouraging multiple uses of public lands. If a wind farm is built on the public land under your control, you will be responsible for overseeing and managing the project. The federal government would receive lease payments and/or royalties from the developer.

1. What are the advantages and disadvantages to the BLM of allowing the development of the wind farm?
2. What are the major issues that the BLM must consider before allowing the development of the wind farm?
3. One of the jobs of the BLM is to protect the public's interest in the land. Will allowing the development of the wind farm be in the best interest of the public?

Developer

As the developer of the wind farm project, you must create a plan that details the advantages of establishing a wind farm in your particular area. You must also be able to answer questions from those groups that might oppose the wind farm. It is important as the developer that you understand the "big picture" of the positive and negative impacts of developing the wind farm.

1. What are the long-term benefits to the community of developing the wind farm?
2. What are the disadvantages? How will potential risks be minimized?
3. How will the environment be protected during the installation, operation, and maintenance of the wind farm?

Investor

An investor is someone who uses his or her money to finance a project, in order to make money later. A developer has approached you with a proposal to build a wind farm in a nearby community. As an investor, you are interested in paying money now to build a wind farm, with the idea that you will earn money later as the wind farm becomes productive. You need to determine the costs, risks, earning potential, and benefits of investing in the wind farm.

1. How much will it cost to build and maintain the wind farm? What costs do you need to consider?
2. How much return of income can you expect from your investment? Over how many years?
3. What are the biggest risks to investing in the wind farm?

Site Planner

The site planner of a wind farm considers many factors to determine the best location for a wind farm. You must take into consideration the important concerns that community members have. You need to determine the optimum areas for the turbines in regard to local weather patterns. You must also take into consideration any other environmental factors that might affect the siting of the wind farm.

1. What information about local and global weather patterns and wind technology must you research before siting a wind farm?
2. What environmental factors must you consider before siting a wind farm?
3. What other factors must you consider? Are there roads and power lines nearby?

Farmer/Rancher

You are a farmer and rancher who has a long-term lease of 10,000 acres of public land that you use to grow crops and graze your cattle. The Bureau of Land Management has informed you that it is considering a proposal to allow a wind farm to be built on part of the land. You think that using renewable energy and having multiple uses of the land are good ideas, but you are concerned about the impact of a wind farm on your crops and animals.

1. What impacts will siting, building, and operating a wind farm have on your crops and cattle?
2. Will you have to reduce the acres of crops you grow or the number of cattle that graze on the land?
3. Are there any benefits to you of building the wind farm on your leased land?

Consumer/Neighbor

You are a neighbor of the farmer/rancher on whose land the wind farm might be built. You have heard that large wind turbines generate a great deal of noise and that concerns you because the chinchillas you raise are very sensitive to noise. You are aware that there have been predictions of blackouts in the near future in your area because of a lack of electricity capacity. You are also wondering how the price of electricity in your area might be affected if a wind farm was installed.

1. How much noise do wind turbines generate?
2. How would a wind farm affect the property values of the surrounding properties?
3. How would local electricity rates be affected by the installation of a wind farm?

Environmentalist

You are very concerned with protecting the environment. You would like to know how wind energy impacts the environment during the manufacture, installation, maintenance, and removal of the wind turbines. Also, there have been reports in the past of wind turbines injuring birds and bats that fly into them. You would like to know how wind energy installations might affect birds and animals in your area. Great Lakes conservation groups have worked hard to keep the great lakes in a natural state. They've historically opposed oil and gas drilling. They have strong citizen support in the state.

1. How would the manufacture and installation of wind turbines affect the local environment?
2. How would the operation of the wind turbines affect the surrounding environment and the plants and animals in the area?
3. Would the amount of electricity generated by the wind turbines be enough to offset the "cost" to the environment?

Economist

An economist is a person who can analyze the financial impacts of actions. The community that will be affected by the development of the wind farm has consulted you. They have asked you to determine the costs of generating electricity from fossil fuels and wind energy and to do a comparison study. This includes comparing construction costs, transmission costs, generation costs, and potential tax credits available for using wind. Many local economies in areas of MI depend on income from tourists/vacationers.

1. How does the cost of using wind to generate electricity compare to other sources?
2. What economic advantages/disadvantages would the wind farm bring to the area?
3. Will the wind farm impact the economy of the area by bringing more jobs to the area?

Utility Company Representative

You are an employee of the local utility company and are responsible for making sure that your utility has the necessary capacity to provide electricity to all of your customers. There is increased demand for electricity in your community and you know you must secure reliable sources of additional generation in the near future. You would be the main purchaser of electricity from the wind farm.

1. How expensive would the electricity be from the wind farm?
2. Will the wind farm produce enough electricity with reliability to meet the growing needs of the community?
3. Will there be additional costs to the utility company that might be passed along to consumers?

Member of the County Commission

The County Commission manages the public services of the community and determines how they are paid for. The County Commission is a political group and must take into consideration all political sides of the issue. You must consider the impacts on the community if the Bureau of Land Management allows the wind farm to be developed in the area.

1. What impacts would the wind farm have on the need to provide local services?
2. What economic impacts would the wind farm have on the local community and taxes?
3. What political impact would supporting the wind farm have on your community?

Useful Web Sites to Visit When Conducting Research

American Wind Energy Association: www.awea.org

Energy Information Administration: www.eia.gov

Bureau of Land Management: www.blm.gov

U.S. Department of Energy - Wind: www.doe.gov/science-innovation/energy-sources/renewable-energy/wind

U.S. Department of Energy - Energy Efficiency: www.doe.gov/science-innovation/energy-efficiency

U.S. Department of Energy, Energy Efficiency and Renewable Energy, Wind Program: www1.eere.energy.gov/wind

APPENDIX N:

Wind Farm Calculator Spreadsheet with Sample Data Entered

Wind Farm Calculator with Sample Data Entered

Students manipulate values in yellow cells by researching information from resources provided, calculating area of full-scale turbine, changing the number of turbines in farm, and entering the wind speed in the area selected from the interactive mapping system (http://www.eia.gov/state/?sid=MI). The spreadsheet makes calculations of the performance of the wind farm based on the entry of those cells using formulas.

Table 18: Wind Farm Calculator Spreadsheet with Sample Data Included

Turbine Performance Calculation	
Efficiency of turbine blades	0.50
Wind speed @ location (m/s)	8.90
Area of full size turbine (m^2) (50m blades if on shore, 80 m blades if offshore)	20,106.00
Power of wind @ location (kW)	8,504.46
Power of single turbine @location (kW)	4,252.23
Turbine Cost Calculation	
Cost of on shore 50m turbine construction ($/kW)	$2,213.00
Opertation and maintenance cost on shore ($/kW-yr)	$39.55
Cost of offshore 90m turbine construction ($/kW)	$6,230.00
Opertation and maintenance cost off shore ($/kW-yr)	$74.00
1.5 MW turbine construction cost (on-shore)	**$3,319,500.00**
4 MW turbine construction cost (off-shore)	**$24,920,000.00**
Wind Farm Cost Calculation	
Number of turbines in Farm	372
Power of wind farm (kW)	1,581,830
20 year cost on shore (construction and op & main)	$1,238,217,515.52
20 year cost off shore (construction and op & main)	$9,276,533,303.38
Total Energy of Wind Farm	
Energy produced by farm in one year (MWh)	13,856,834
Cost of electricity ($/kWh)	$0.1098
Value of energy produced in one year	**$1,521,480,319.32**
Michigan net electricity generation (needs) per year (MWh)	108,166,078
% of total electrical needs Provided to MI	**12.81%**
Michigan Electricity Generated from Coal (MWh/yr)	52,470,940
Amount of Coal used for power generation in a year (tons)	29,795,605
Amount of CO2 released from coal plants every year (tons)	85,215,430

Table 18: (cont'd)

Amount of coal saved from wind farm construction (tons)	**7,868,598**
Amount of CO2 saved from being released every year (tons)	**21,087,843**
% decrease in coal consumption	**26.41%**

On shore Pay off time (yrs)	**0.81**
Off shore pay off time (yrs)	**6.10**

APPENDIX O:

Ohm’s Law Homework

Ohm's Law, Power and Electrical Energy

Define and state what unit each is measured in:

Electrical current:

Voltage:

Resistance:

Review: All should be on your notecard!

Power is the rate at which work is done, or the rate at which energy is transferred. It is measured in watts (which is a Joule/second)

$P = \frac{W}{t} \quad OR \quad P = \frac{\Delta E}{t}$

Energy can be found by $\Delta E = P \cdot t$

If the power is watts and the time is seconds, this will give you Joules. If you want kilowatt-hours of energy, convert the power to kilowatts and have time in hours.

Electrical power is $P = iV$

Practice:

If a small appliance is rated at a current of 10 amps and a voltage of 120 volts,

the power rating would be ______ Watts. (P = I V)

What is the resistance of the appliance? (Ohm's law)

How many Joules of energy will it use in 2 minutes at max power?

If a clock expends 2 W of power from a 1.5 V battery,

What amount of current is supplying the clock?

What is the resistance of the clock's circuits?

Tommy runs his juicer every morning. The juicer uses 90 W of Power and the current supplied is 4.5 A.

How many volts are necessary to run the juicer?

What is the resistance of the juicer?

Amanda's hair dryer requires 11A of current from a 110 V outlet.

How much power does it use?

A DC electric motor transforms 1.50 kW of electrical power into mechanical form. If the motor's operating voltage is 300 volts,

How much current does it "draw" when operating at full load (full power output)?

How many kilowatt-hours of energy will it use in a day?

How much will it cost to run the motor at $.10 per kilowatt-hour?

A 100 Watt lightbulb is plugged into the wall supplying 110 V.

What is the resistance of the bulb?

How much current flows through the bulb?

How much energy will it use in 1 day:

In Joules

In kilowatt-hours

Ohm's Law Practice Worksheet

An alarm clock draws 0.5 A of current when connected to a 120 volt circuit. Calculate its resistance.

A subwoofer needs a household voltage of 110 V to push a current of 5.5 A through its coil. What is the resistance of the subwoofer?

A walkman uses a standard 1.5 V battery. How much resistance is in the circuit if it uses a current of 0.01A?

A circuit contains a 1.5 volt battery and a bulb with a resistance of 3 ohms. Calculate the current.

What current flows through a hair dryer plugged into a 120 Volt circuit if it has a resistance of 25 ohms?

If a toaster produces 12 ohms of resistance in a 120-volt circuit, what is the amount of current in the circuit?

A 12 Volt car battery pushes charge through the headlight circuit resistance of 10 ohms. How much current is passing through the circuit?

How much voltage would be necessary to generate 10 amps of current in a circuit that has 5 ohms of resistance?

An electric heater works by passing a current of 100 A though a coiled metal wire, making it red hot. If the resistance of the wire is 1.1 ohms, what voltage must be applied to it?

A light bulb has a resistance of 5 ohms and a maximum current of 10 A. How much voltage can be applied before the bulb will break?

What happens to the current in a circuit if a 1.5-volt battery is removed and is replaced by a 3-volt battery?

What happens to the current in a circuit if a 10Ω resistor is removed and replaced by a 20Ω resistor?

APPENDIX P:

Exploring Solar Power Activity

Exploring Solar Power

Students use Elenco® Electronic Inc. Solar Deluxe Educational Kit and digital multimeters

Students use the included solar array to complete *Solar 1, Solar 2, Solar 5, and Solar 9* from page 18-27 of the *Exploring Photovoltaics Student Guide*

Accessed from *http://www.need.org/files/curriculum/guides/Photovoltaics%20Student%20Guide.pdf*

Solar 1: Students measure current, voltage and power of each of three panels in the solar array

Solar 2: Students wire the three panels in series and connect to a light bulb to measure current, voltage and power.

Solar 5: Students vary the distance of the series array to the light source and measure current, voltage and power.

Solar 9: Students wire the three panels in parallel and connect to a lightbulb to measure current, voltage and power.

APPENDIX Q:

Wiring Solar Panels Worksheet

Wiring Solar Panels Worksheet

Students Complete *Activity 6: Series and Parallel Wiring*

Source: Bonneville Environmental Foundation

Accessed from:
http://www.solar4rschools.org/sites/all/files/Series%20and%20Parallel%20Wiring.pdf

In the activity, students are given arrays of individual solar panels with specific voltage and current ratings. They are given the task of connecting them together in combinations of series and parallel by drawing wires to the leads that produce a desired output voltage and current of the array.

APPENDIX R:

Climate Change Survey

<u>Global Climate Change Survey</u>

1. Carbon dioxide levels in the atmosphere prevent some of the sun's energy from radiating into space.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

2. Burning of fossil fuels releases carbon dioxide and other gases into the atmosphere.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

3. The Earth's atmosphere is large enough where human activity cannot possibly cause a significant change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

4. The Earth goes through natural cycles of heating and cooling over the course of millions of years.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

5. I am unsure if global warming/climate change is happening.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

6. Assuming global warming/climate change is happening, it is very likely affected by humans.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

7. The evidence for climate change is unreliable.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

8. A significant number of scientists have doubts about the evidence for global climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

9. A significant number of citizens have doubts about the evidence for climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

10. Experts are agreed that climate change is a real problem.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

11. Global warming/climate change, if it is happening, is so slow that humans do not have to worry about it for hundreds of years or longer.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

12. The last winter was one of the coldest on record. This is evidence against global warming/climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

13. Do you think global warming should be a low, medium, high, or very high priority for the President and Congress?

1	2	3	4	5	☐ I don't know
Low		Medium		High	

14. If I come across information about climate change I tend to look at it.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

15. Decisions and actions I make every day can contribute to climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

16. I feel a moral duty to do something about climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

17. Jobs today are more important than protecting the environment for the future.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

18. I feel I am educated enough to form my own opinion about global climate change.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

19. By circling the number, please indicate how much you would trust information about climate change if you heard it from...

1) A lot 2) A little 3) Not very much 4) Not at all

A family member or friend	1	2	3	4
A scientist	1	2	3	4
The government	1	2	3	4
An energy supplier	1	2	3	4
And environmental organization	1	2	3	4
The media	1	2	3	4

20. How can turning on a light at home put CO_2 into the atmosphere?

Table 19: Scoring Rubric for Climate Change Survey

Question	2	1	0
Q20	Properly addresses that power plants use fossil fuel to generate electricity which is transported to their home and "used" by turning into light and heat. Therefore the light came from burning fossil fuels at the plant	Partially addresses that power plants use fossil fuel to generate electricity which is transported to their home and "used" by turning into light and heat. Therefore the light came from burning fossil fuels at the plant	Does not address the use of fossil fuels by power plants and how that is the source of the bulb's energy

APPENDIX S:

Energy Pre/Post Test

Energy Pre/Post Assessment

1. What are the 6 main forms of energy?

2. What is the difference between a renewable and non-renewable source of energy? Give examples of each.

3. Why is it important to develop alternative energy sources? (support with at least two reasons)

4. If the law of conservation of energy states that it cannot be created or destroyed, why should we worry about running out of energy?

5. How does your quality of life depend on energy?

6. How does efficiency play a role in energy supply and consumption?

7. How does the energy from a coal power plant come from the sun? Include an energy transformation diagram.

8. Fossil fuels are abundant and we don't have to worry about running out for a very long time.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

9. It is not feasible (too expensive) to stop using fossil fuels in the *near* future

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

10. Some forms of renewable energy are currently comparable in cost to fossil fuels.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

11. Continued advances made by scientists and engineers can find affordable solutions to the dependence on fossil fuels for energy.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

12. If I come across a news story, article, etc. concerning energy, I will tend to look at it.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

13. The development of alternatives to fossil fuels is essential for the continued advancement of mankind.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

14. It is necessary to develop alternative energies now before it is too late.

1	2	3	4	5	☐ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

Table 20: Scoring Rubric for Energy Pre/Post Test

Question	2	1	0
Q1	All six listed	3-5 listed	1-2 listed
Q2	Definitions of renewable and non-renewable used properly (non-renewable cannot be replaced as quickly as it is used, renewable energy can). Proper examples of each are given.	Definitions of renewable and non-renewable used well. Examples are incorrect or missing.	Response does not show knowledge of what makes a resource renewable or non-renewable
Q3	Response contains a statement based on evidence of climate change, increasing demand, and diminishing supply. (At least two must be addressed)	Response contains a statement based on one piece of evidence of climate change, increasing demand, or diminishing supply.	No evidence given to support a change to renewables.
Q4	Statement refers to the forms of energy changing. In the process some energy is turned into other forms. Some forms are useful and some are not (thermal energy) easily recoverable or useful but the amount is the same.	Statement only addresses energy in the form of fossil fuels running out. (We will run out of oil etc.)	Statement supports the notion of energy being used and/or destroyed in the process.
Q5	Response connects energy to wealth and well-being. Energy is needed for a society to advance and have a high standard of living (health, wealth, education etc.)	Response makes some connection to energy contributing to progress.	Response makes no meaningful connection between energy and standard of living.
Q6	Response points out that increased demand can be met by using what we have more efficiently with some reference to conservation practices and not being wasteful.	Response includes responsible/non-wasteful energy use.	Response does not address wasteful energy use as a problem to be addressed.

Table 20: (con't)

Q7	Response explains the process of energy conversion from solar to chemical in coal and how a powerplant burns the coal to generate electricity. A complete energy transformation diagram is included	Response correctly relates energy from the sun in energy in coal. Mistakes possible in transformation diagram or in explanation (only one)	Response incorrectly relates solar power to a coal plant.

APPENDIX T:

Engineering Design Pre and Post Assessments

<u>Engineering Design Pre Assessment</u>

1. What does a scientist do?

2. What does an engineer do?

3. I feel that I understand what the engineering process is/what an engineer does.
   1 2 3 4 5 ☐ I don't know
   strongly disagree — neither agree/ nor disagree — strongly agree

4. I would consider engineering as a career/major in college.
   1 2 3 4 5 ☐ I don't know
   strongly disagree — neither agree/ nor disagree — strongly agree

5. I feel that well-trained engineers are important to the future and beneficial to society.
   1 2 3 4 5 ☐ I don't know
   strongly disagree — neither agree/ nor disagree — strongly agree

Table 21: Scoring Rubric for Engineering Design Pre Assessment

CATEGORY	2	1	0
Q1	Properly addresses that scientists answer questions through using the scientific process. Hypotheses are tested and conclusions are drawn from evidence.	Addresses only the scientific method of answering questions	Does not correctly explain what a scientists does.
Q2	Properly addresses that engineers solve problems using the engineering design process. Elements of the design process are included in response.	Addresses that engineers use the engineering design process.	Does not correctly explain what an engineer does.

Engineering Design Post Assessment

1. What does a scientist do?

2. What does an engineer do?

3. Explain how, over the course of the past two units, you have analyzed a major global challenge (energy crisis) to specify criteria and constraints for solutions that account for the wants and needs of society.

4. Explain how, over the course of the past two units, you have designed a solution to a complex real-world problem (energy crisis) by breaking it down into smaller, more manageable problems that can be solved through engineering.

5. Explain how, over the course of the past two units, you have evaluated a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints. (decision matrix)

6. Explain how you have used models to help you determine or estimate the impact of proposed solutions to a complex real-world problem. Models may be computer models/simulations, or mathematical models and calculations, or physical models used to simulate systems. Address as many as you can.

7. ~~What science concepts did you use to design your wind power project? List as many as you can think of.~~

8. I feel that understand what the engineering process is/what an engineer does.

1	2	3	4	5	□ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

9. I would consider engineering as a career/major in college.

1	2	3	4	5	□ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

10. I feel that well-trained engineers are important to the future and beneficial to society.

1	2	3	4	5	□ I don't know
strongly disagree		neither agree/ nor disagree		strongly agree	

Table 22: Scoring Rubric for Engineering Design Post Assessment

Question	2	1	0
Q1	Properly addresses that scientists answer questions through using the scientific process. Hypotheses are tested and conclusions drawn from evidence	Addresses the scientific method of answering questions	Does not correctly explain what a scientists does.
Q2	Properly addresses that engineers solve problems using the engineering design process. Elements of the design process are included in response.	Properly addresses that engineers use the engineering design process.	Does not correctly explain what an engineer does.
Q3	Description connects the work performed in class to the performance expectation in question	Some connections	Description does not connect the work performed in class to the performance expectation in question
Q4	Description connects the work performed in class to the performance expectation in question	Not available	Description does not connect the work performed in class to the performance expectation in question
Q5	Description connects the work performed in class to the performance expectation in question	Not available	Description does not connect the work performed in class to the performance expectation in question
Q6	Description connects the work performed in class to the performance expectation in question	Not available	Description does not connect the work performed in class to the performance expectation in question
Q7	A complete list of the major concepts is included:	A partial list of the concepts is included:	Very few listed

APPENDIX U:

Electricity Assessment

Electricity Assessment

1. What do you know about: (include units)
    a. Electric current
    b. Voltage
    c. Resistance
    d. How are they related?
2. What are the differences between series and parallel circuits?
3. What happens to voltage and current when solar cells, batteries, or other voltage sources are wired in
    a. Series
    b. Parallel

4. ~~What is alternating and direct current and give examples of each~~.

~~5. How can electricity be generated? How does the process work? (use science concepts)~~

6. What is the difference between electric power and electric energy?

7. You have four 1.5 V batteries and a 10 Ω resistor.
   a. Draw a circuit below using all four batteries that has 3 V supplied to the resistor.

   b. Calculate the current through the resistor.

   c. Calculate the power dissipated in the resistor.

   d. Calculate the energy used by the resistor in 1 day in joules <u>and</u> kilowatt hours.

Table 23: Electricity Assessment Scoring Rubric

Question	2	1	0
Q1a	Response correctly describes electric current as the flow of electric charges and includes units.	Response describes electric current with some minor mistake OR does not include units.	Response does not correctly describe current.
Q1b	Response correctly describes voltage and includes units.	Response describes voltage with some minor mistake OR does not include units.	Response does not correctly describe voltage.
Q1c	Response correctly describes resistance and includes units.	Response describes resistance with some minor mistake OR does not include units.	Response does not correctly describe resistance.
Q1d	Response includes ohm's law either as an equation with variables or units. Ohm's law described in words (directly proportional, inversely proportional)	Relationship between at least two of the variables is correct.	Ohm's law is not listed or described
Q2	Series and parallel circuits are described correctly with clear differences between the two.	The circuits are not fully described or differences are present but may be unclear.	Descriptions are incorrect.
Q3a	Series circuits the voltage is added and the current remains the same	Either voltage or current is missing or incorrect	Relationships are incorrect
Q3b	Parallel circuits the voltage remains the same and the current is added.	Either voltage or current is missing or incorrect	Relationships are incorrect
Q4	Descriptions of AC and DC are accurate with proper examples of each.	Descriptions of AC and DC are accurate may have a mistake on examples	Descriptions of AC and DC are incorrect
Q5	The process of inducing current by changing magnetic fields (electromagnetic induction) is properly described.	Statement of the parts of generator is present but no description of the science concepts.	Incorrect or absent description. May simply say a generator.

Table 23: (cont'd)

Q6	Power is described as the rate of energy transfer or the rate at which electricity does work. Energy described as the ability to do work/transfer energy.	Either power or energy description is incorrect.	Both concepts are not described correctly.
Q7a	Proper diagram showing a parallel connection of two systems of two batteries in series with each other with a complete circuit through the resistor.	N/A	Incorrect/absent circuit
Q7b	3 V / 10 Ω = .3A or 300mA Or other correct use of Ohm's law based on incorrect circuit in part a	May have incorrect units	Incorrect/absent
Q7c	Proper use of P=IV = (.3A)(3V)=0.9W Or other correct use using incorrect values from part a&b.	May have incorrect units	Incorrect/absent
Q7d	Proper use of E=Pt=(0.9W)(86,400s)=77,760J and $(9.0\times10^{-4}$kW)(24hr)=2.16×10^{-2} kWh	May have incorrect units or incorrect use/conversion of time. May have one of the calculations incorrect (J or kWh)	Incorrect/absent

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