THE DESIGN PROCESS IN AN EIGHTH GRADE SCIENCE CLASS

by

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DEDICATION

I would like to present a sincere appreciation to the Master of Science in Science Education (MSSE) program through Montana State University. Whether climbing through Glacier National Park, constructing a mouse trap car at my dining room table, studying the physics of avalanches from 500 feet above sea level, or communicating with other educators around the country and world, I gained invaluable opportunities that allowed me to grow personally and professionally. I am extremely grateful to my project advisor, John Graves, for his continued encouragement through the writing process. In my push to help students become more resilient, John, kindly provided the support I needed. I would like to thank Nick Childs too, not only as my science reader, but for providing the spark to design some crazy engineering projects to convert one form of energy to another. There is nothing like watching your student successfully ride a bike across a pond in April. Thank you, Diana Paterson, for your speedy answers to my questions and your beautiful reminders. I have been blessed to meet a variety of talented individuals and colleagues.

I would like to thank my family and friends for their continued support. Especially, I would like to thank my brother, Mike Harper, for his countless hours of designing a photoreceptor with me. To my great friend and walking buddy, Andrea Wilford, thank you for being my sounding board. Finally, I would like to thank my husband, Jim Joslyn, for his patience and encouragement.

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ABSTRACT

Engineering provides a framework in which students can test their own developing scientific knowledge and apply it to practical problems. There are many parallels to the application of science principles and engineering practices. Both rely on developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematical and computational thinking, engaging in arguments from evidence, and obtaining, evaluating and communicating information. While some students become engaged in the design process, scientific principles can be excluded from the engineering aspects. One unit of study was compared – a nontreatment group using no mathematics and computational thinking to facilitate the design process and a treatment group relying upon mathematics and computational thinking to the design process. The treatment unit required students to collect data and define scientific principles within the design process. Students were given pre-, mid-, and post-tests for the unit of study, an interest survey, and interviews were conducted. Both groups of students indicated the importance of using data in the design process. When students were required to use mathematics and computational thinking in the design process, the results suggested that students exhibited a slight improvement in test scores on the multiple choice and short answer responses. In the students' final reflections, many students expressed a greater appreciation for engineering.

INTRODUCTION AND BACKGROUND

Muscatine is a small city of 25,000 people in southeast Iowa along the Mississippi River. The ethnic diversity of the district includes 63% Caucasian, 28% Hispanic, 4% African American, 4% Multiracial and 1% other. Central Middle School's ethnic diversity differs slightly: 60% Caucasian, 29% Hispanic, 6% African American, 3% Multiracial, and 1% Asian. District wide, 52% of the students receive free and reduced lunch. Approximately 12% of the students are talented and gifted. Last year 81.8% of the students graduated from Muscatine High School as compared to 91% statewide (Educate Iowa, 2019*)*.

Students are required to take eighth grade science. The eighth-grade science course, an inquiry-based approach, focused on the 5E learning model: Engage, Explore, Explain, Elaborate, and Evaluate. The course covered force and motion, kinetic energy, sound/light waves, weather, ocean currents, human impact on the environment, fossil record, and natural selection. A significant proportion of class time was devoted to hands-on, guided inquiry laboratory investigations, including several units with real world applications.

Each unit began with the presentation of some phenomena. An example would be that of a cart rolling down an incline. Students were asked to make observations about the demonstration. As a class, students decided upon a question they intended to answer about the motion. Students then devised an experiment with group members to help answer this question. This process of designing and conducting experiments was a key part of this class. After performing the experiment students presented results to the other groups and defended their results. The other groups critiqued both the procedure and findings. Students decided upon a concise explanation for the events observed as an entire class. Additional labs throughout the unit either expanded on the model or were used to create new models for situations related to the initial experiment. The students actively participated with each other through collaboration and discussion daily.

In August 2015, the Iowa State Board of Education adopted the Next Generation Science Standards (NGSS) with some modifications. The state developed a timeline for the adoption of NGSS with full implementation by the start of the 2018 – 2019 school year. Modifications of NGSS reflected that only the performance expectations be adopted. In order for students to be proficient with the performance expectations, three-dimensional learning was emphasized. Three-dimensional learning promoted that science was both a body of knowledge and evidence-based system that extended, refined and revised knowledge. Aspects of three-dimensional learning included crosscutting concepts, disciplinary-core ideas, and science and engineering practices.

Due to the adoption of the standards, I included more engineering practices in my classroom. The engineering practices were not treated separately from the other science practices, nor can any of the science practices be treated separately. As I included more engineering practices, I noticed that students were able to work through the design process. However, the students still needed to show both qualitative and quantitative improvements throughout the design process. In addition, the students were able to explain the science separately, but resisted showing understanding of scientific concepts when constraints or challenges were added. Although mathematical modeling was emphasized, I wanted the students to be able to carry over the mathematical concepts for their performance expectation. Upon introducing engineering activities, students in eighth grade science overwhelmingly requested to complete similar activities.

The purpose of this study was to engage students in engineering practices to enhance their understanding after building conceptual models. After discussing with my principal, my professional learning community, and instructional coaches, I came up with the following questions to address my research: what effect does the design process have on eighth-grade science students? I would like to ask the sub question what effects do the addition of computational thinking and mathematics add to the design process?

CONCEPTUAL FRAMEWORK

The implementation of the Next Generation Science Standards (NGSS) has produced shifts in instructional practices (National Research Council, 2015). The final draft of the NGSS was published in 2013. Collaboration between 26 lead states provided student benchmarks by framing three-dimensional learning through science and engineering practices, crosscutting concepts, and disciplinary core ideas. The practices identified included asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information. Crosscutting concepts applied and emphasized a worldview throughout all fields of science, including patterns, cause and effect, scale, systems and system models, energy and matter, structure and function, and stability and change. The disciplinary core ideas should meet at least two of the four criteria:

- Ensure comprehensive importance across multiple sciences or engineering disciplines or be a fundamental organizing concept of a single discipline;
- Specify a significant pathway for understanding or investigating more multifaceted ideas and problem-solving;
- Relate to student interests and life experiences or connect to societal or personal concerns that require scientific or technological knowledge;
- Extend over multiple grades with increasing depth and complexity.

The disciplinary ideas are grouped into four areas: physical science, life science, earth and space science, and engineering, technology, and application of science (NGSS, 2013).

A unit of study often began with the presentation of a phenomena. Phenomena could be observable events occurring in the universe, leading to explanations or predictions based on observations. Studying phenomena provided authentic engagement, generating student approaches of inquiry and creating opportunities for learning (NGSS, 2016). Providing students with a photograph of a rainbow and asking students what observations they could make about rainbows and a cause of rainbows was an example of studying phenomena.

Supportive of the NGSS, the modeling instruction method was founded in the science practices. A research-based pedagogy developed in the 1980s, modeling was an approach that integrated both a student-centered teaching method and a model-centered curriculum. Modeling instruction employed structured inquiry strategies to teach basic skills in mathematical modeling, proportional reasoning, estimation, and data analysis. Critical thinking and the ability to articulate rational arguments from evidence were emphasized in modeling instruction (Haag & McGowan, 2014).

Model-based inquiry was defined as any application that assembled information resources, learning activities, and instructional strategies intended to facilitate mental model building in individuals and among groups of learners (Gobert & Buckley, 2000). Taking a complex concept that is difficult to manage by using examples relevant to the learner to improve better understanding, model-based inquiry used existing model inquiries, inquiries to revise models, models to construct explanations, models to unify understanding, and engages in argumentation (Passmore, 2014). Model-based inquiry provided a method to promote student learning about science content, science process, and the nature of science in a more complete and relevant manner (Campbell, Zhang, & Nielson, 2011).

Similar to model-based inquiry, engineering practices also included a design process. The design process encompassed a series of that steps that guides engineering teams through problem solving. An iterative process, students repeated the steps as many times as necessary to make improvements along the way. Students were encouraged to learn from their mistakes. The National Research Council, NRC, (2012) provided a rationale for including engineering practices in NGSS:

> Engineering and technology… are included in the framework for several reasons. First, the committee thinks it is important for students to explore the practical use of science… Second, … these topics typically do not appear elsewhere in the curriculum and thus are neglected if not included in science instruction… Finally, engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science – and, for many, their interest in science – as they recognize the interplay among science engineering, and technology (p. 12).

Engineering practices both delivered the applications of science and provided students a path to improve their understanding of the content. There were many parallels and complements between engineering and technology in science education. Both engineering and technology developed and used models, planned and carried out investigations, analyzed and interpreted data, used mathematical and computational thinking, engaged in arguments from evidence, and obtained, evaluated, and communicated information (NRC, 2012).

Science and engineering practices are complementary. While science works to understand phenomena, engineering designs a solution to a problem. A scientist might study the properties of reflection or refraction of light through various mediums while an engineer could use the knowledge from light properties and create a design for a security system using lasers and photoreceptors. In science students collected and used data to find relationships or explain natural phenomena (Harkema, Jadrich, & Bruxvoort, 2012). In engineering, students developed a product, process, or a system to meet a challenge or solve a problem. While science resulted in a comprehensive understanding of concepts, engineering resulted in specific solutions from defined conditions. To support the large number of teachers who lack engineering education, Cunningham and Carlson (2014) clarified the differences between science and engineering practices.

Like science, engineering focused on multiple pathways in the design process. Berland, Stiengut, and Ko (2014) suggested there was not a single engineering design process. The engineering process began with defining the problem. Engineers asked questions to define the problem, established conditions for a successful solution, and distinguished limitations (NRC, 2012). Engineers engaged with math and science content while attempting engineering work (Berland et. al., 2014). Avoiding focusing on one idea too early because other ideas could be overlooked, engineers generated multiple solutions and developed systems for choosing between these solutions (Eastman, McCracken, & Newsletter, 2001).

Multiple opportunities to integrate math and science content in the design process existed, particularly in the comparison between competing designs and quantifying measurable success. Engineers constructed models of an existing system or parts of a system or developed mathematical models to analyze their data. Modeling provided a mechanism for learning math and science content. Engineering was an iterative process, revisiting previously completed steps to improve the design. Often repetition of steps or processes occurred, and some steps required revision of mathematical models (Berland, Steingut, & Ko, 2014). The engineering design process was a series of steps that engineering teams use to solve problems. The steps included ask or identify the need and constraints; research the problem; imagine or develop possible solutions; plan or select a promising solution; create or build a prototype; test and evaluate the prototype; and improve or redesign as needed (Teach Engineering, 2019). The steps were not linear, as seen in Figure 1, allowing for continuous design improvement.

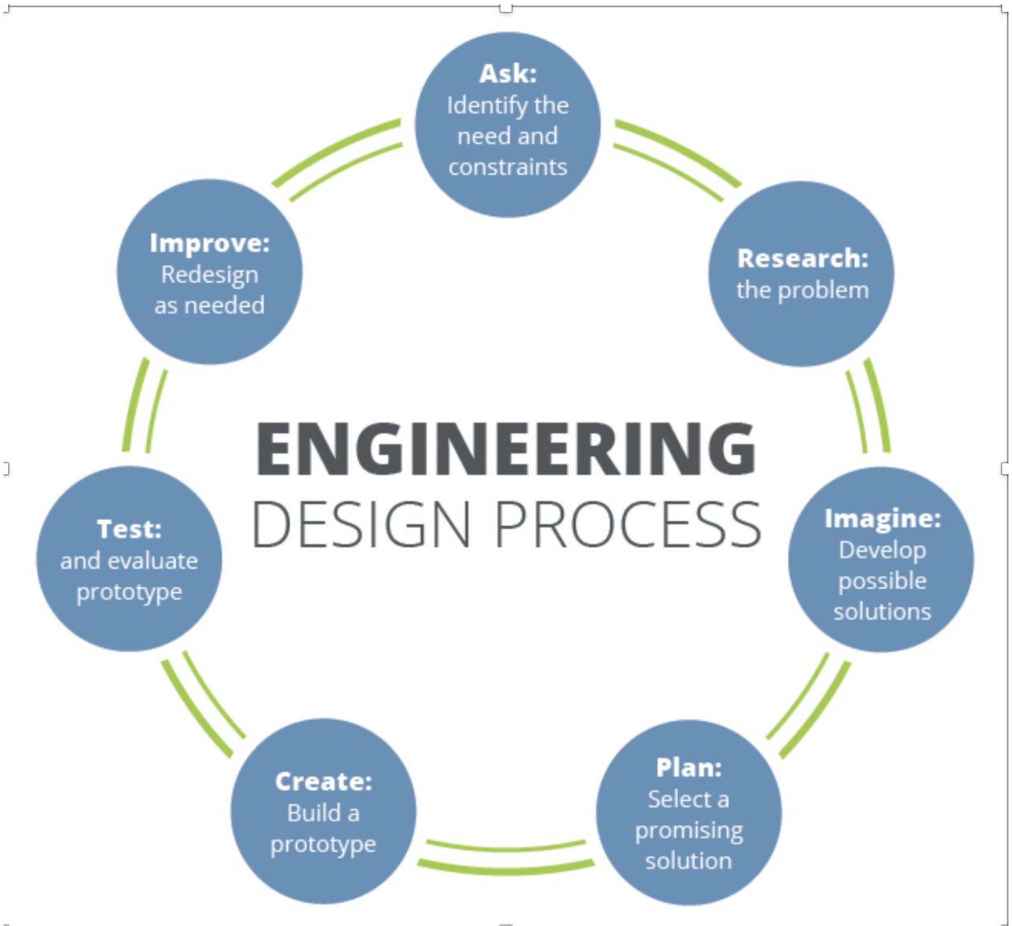

Figure 1. The design process (Teach Engineering, 2019).

According to a summary from the National Academies of Engineering and National Research Council joint report, engineering in the K-12 classroom was expected to introduce students to the field of engineering and provide opportunities for students to engage with science content in an applied context. (National Academies of Sciences, Engineering, and Medicine, 2018). Boesdorfer and Greenhalgh (2014) provided approaches to incorporate engineering practices into science curriculum. Educators could rework engineering model experiments to explicitly include the engineering framework, ideas, and terminology. Engineering was not just building something, rather, engineering was defined as a method to solve a problem. Encouraging a design brief provided a thinking tool to identify a problem to be solved. The design brief included the situation, problem, materials, and resources available to students, constraints of the project, including time or cost associated with the project, and criteria for evaluation (Boesdorfer, 2014).

Engineering required students to encounter a challenge, perform an explicit task, construct an alternative possibility, or solve a problem. Students could demonstrate their knowledge and gain experience with science and engineering practices using an open-ended problem-solving process. Gilbert and Wade (2014) concluded that using the science and engineering practices was an effective approach to teaching performance expectations. Students engaged in leading discussions and communicated distinctions between science and engineering practices.

NGSS provided a framework in which students could test their own developing scientific knowledge and apply it to practical problems. There are many parallels to the application of science principles and engineering practices. Both relied on developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematical and computational thinking, engaging in arguments from evidence, and obtaining, evaluating and communicating information.

METHODOLOGY

In order to assess the effects of the design process, all eighth-grade students were taught using Stemscopes units Properties of Visible Light and Modeling Light Waves

(Stemscopes, 2018). Upon completion of the Properties of Visible Light and Modeling Light Waves units, the students were asked to build a security system that employed the design process to solve a real-world problem. During the engineering design process, the treatment group relied upon more computational thinking and mathematics to measure the angle of incidence and angle of reflection. The nontreatment group completed the same engineering exercise without the computational thinking and mathematics, and the nontreatment students were not asked to measure the angle of incidence and angle of reflection. This project took place over the course of eight weeks. Units covered included light and waves. The research methodology for this project received an exemption by Montana State University's Instructional Review Board and compliance for working with human subjects was maintained (Appendix A).

A total of forty-four eighth grade students participated in this project. A slight majority of the population were male, 57%, while the remainder of the class was female, 43%. Twenty-five percent of the population were minority students while 75% were Caucasian. Twenty-seven students in my first period eighth grade class were selected as the nontreatment group. Seventeen students in my fifth period eighth grade class were selected as the treatment group.

At the start of the school year, students completed an Attitudes and Approaches to Problem Solving Survey (Appendix B). The survey was also administered at the end of the study to determine changes in attitudes and approaches to solving problems. The survey was scored using a Likert scale with the responses Strongly Agree, Somewhat Agree, Neutral or Don't Know, Disagree Somewhat, or Strongly Disagree. Normalized gains were calculated and were reported as low (<30%), medium (30%-60%) and high (>60%) (Hake, 1998).

The students were taught the design process after the Attitudes and Approaches to Problem Solving Survey was administered. The students were provided posters of the design process (Teach Engineering, 2019). The engineering process was explained and modeled to the students.

Each student was issued a Chromebook and the Stemscopes curriculum was applied. A significant portion of class time was devoted to hands-on, guided inquiry laboratory investigations. Several activities within the unit involved real world applications. Upon the completion of the unit, the students participated in the design of a security system. I asked the students to use the properties of light to solve the following challenge: "A mummified troll was discovered this summer at our school and it has generated lots of interest worldwide. The principal asked us to design a security system that alerts the police if someone tries to pilfer our prized possession. How can we construct a system that allows visitors to view our artifact during the day, but invisibly protects it at night in a cost-effective way?" (Teaching Engineering, 2014). Like engineers, students were asked to apply their understanding of scientific light and laser properties to address a real-world challenge—designing and building an invisible security system that was safe to both users and intruders (Figure 2).

Figure 2. Students security system (Reohmerman, 2019).

Before the waves and light unit began, students took the Properties of Visible Light Multiple Choice and Short Answer Assessment consisting of ten multiple choice questions and five short answer questions (Appendices C & D).

I began Properties of Visible Light unit with two investigative phenomena by showing the students a blurred image under water and an image of a rainbow (Figure 3). The students were asked why the image appeared blurry and what causes rainbows. Through the Rainbow Preconception Probe (Appendix E), students were asked to respond to conversations about light properties. Students were then asked to identify how light interacts with materials, such as wood, glass, plastic, or walls. Using mirrors and lasers, the students developed a model to describe how light was reflected or transmitted through

Figure 3. Image of rainbows over Victoria Falls, Zimbabwe .

a laser light maze. Students then used a computer simulation (Stemscopes, 2018) to model the light path between transparent materials, and the frequency of different colors of light. Exploring how colored lights appeared differently, the students described the behavior of light when shining light on various colors with colored filters. The students investigated the interactions of visible light waves, including reflection, refraction or absorption with various materials. Using a computer simulation, the students created bar charts to explore relationships between various medium and the refraction of light. In another investigation, the students observed how red, green, and white light behaved when shined through prisms. Throughout the unit, the students journaled their vocabulary into their science logs and recorded observations. Supplemental readings were provided for instructional purposes, including group discussions of the readings. Students were then assessed with the same Properties of Visible Light Assessment and the results were analyzed by normalized gains (Appendices C & D).

Upon completion of the above activities, all students participated in an engineering activity. The students were introduced to the idea of developing an invisible security system to protect the school’s troll doll. When presented with the challenge, the students generated ideas individually, as a team, and finally as a class. During the process of identifying the need, the students defined the challenges to be considered in the design process. The properties of light, including, absorption, reflection, transmission, and refraction of light were reviewed. Safety concerns and real-world laser applications were also detailed prior to independent research of several types of lasers and laser functions.

The students were provided with 12 two-foot PVC pipes and 12 connectors to construct a two-by-two-by-two-foot cube. Students were given a choice of lasers, duct-tape, eight mirrors, and a photoreceptor (Figure 4) to build their security system. Students received the Security System Design Rubric at the beginning of the project (Appendix F). The students were given one full week to work on the project plus an additional day to present their design.

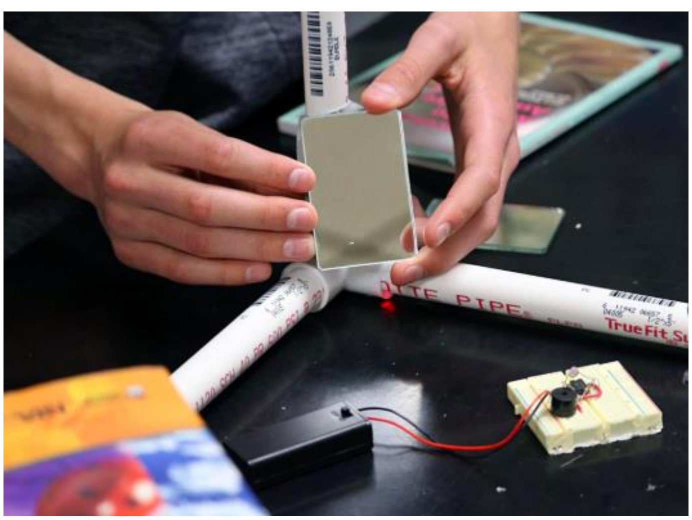

Figure 4. Image of students aligning mirror with laser and photoreceptor (Reohmerman, 2019).

To add computational thinking and mathematics to the design process, the treatment group was asked to include angles in their drawings and representations. The students measured the angles of incidence and angle of reflection using string and the level on their smart phone (Appendix G). The nontreatment was not required to use mathematics and computational thinking and the nontreatment group did not measure the angles. The students were divided into teams of four. The nontreatment class had only one group of three students, with a total of seven groups. The treatment class had two groups of three, with a total of five groups. The groups were picked by the instructor. The treatment and nontreatment groups presented their findings to the class and were scored according to the Security System Design Rubric. The average scores were compared on a bar chart.

The students completed the Security System Interview Questions (Appendix H) after the unit. The purpose of the questions was to provide qualitative evidence in student motivation to problem solving events. In addition, students were specifically asked which activities supported their preparation for the multiple choice and short answer questions. The responses were analyzed for trends and used as evidence to support claims that resulted from other data sources.

The Properties of Visible Light Assessment was administered as a post-test. The mid-test and post-test results were compared and analyzed by normalized gains (Appendix C & D)

Upon completion of the groups' presentations, students were asked to complete the Security System Reflection questions (Appendix I). The answers the questions were analyzed for trends or patterns to characterize the treatment group using measurements and the nontreatment group without measurements.

Throughout the unit an instructional coach recorded observations of the students working on their security systems. Observations and quotes were made randomly by the instructional coach for the nontreatment group (Appendix J) and the treatment group (Appendix K)

The triangulation matrix shown in Table 1 outlined the sources of data that were identified for each question. Triangulation of data provided a means to infer the effects of the intervention and to reduce incorrect analysis of the data. Data were collected from both the treatment and nontreatment units to allow for comparison.

In order to determine the effects of adding computational thinking and mathematics in the engineering practices to the light unit, data were collected using pre-, mid- and post-assessments including both multiple choice and short answer questions, (Appendices C & D), and lab reports with rubrics (Appendix E). The effects of adding engineering practices on student understanding were assessed by means of attitude surveys, interviews, student self-assessment, perceived student learning, and classroom observations regarding student performance (Appendices H, I, J & K). Student engagement was represented through the combination of my own observations and student perceptions. Collection of data from both units was critical to establish the effects of the interventions between the two units.

Table 1
Triangulation Matrix

Research Questions	Data Source 1	2	3
What effect does the design process have on the eighth-grade science classroom?	Pre-,mid-, and post-unit assessment, multiple choice and short answer	Lab report presentation	Observations from instructional coach
What effect does computational thinking and mathematics add to the design process?	Interview questions	Attitude survey (pre and post)	Student self-reflection

DATA AND ANALYSIS

The results from the pre-, mid-, and post- Properties of Visible Light Assessment indicated that students had higher scores (*N=44*) (Figures 5 & 6). In both the treatment (*N*=17) and nontreatment groups (*N*=27) students showed medium normalized gain for the multiple-choice assessment and medium-high normalized gains for the short answer responses (Table 2 & Table 3). Students in the treatment group showed a low normalized gain of 0.35 while the nontreatment group showed a very low normalized gain of 0.08 on the multiple-choice test from the mid- to post-test. The short answer questions indicated a low normalized gain of 0.25 for the treatment group and a low normalized gain of 0.17 for the nontreatment group for the short answer responses.

Table 2
Average Normalized Gains from Pre to Mid to Post- Multiple-Choice Assessment, Treatment (N=17), Nontreatment (N=27)

Group	Pre-Average Score	Mid-Average Score	Average Gain (pre to mid)	Post-Average Score	Average Gain (mid to post)
Treatment	6.71	8.47	.53 medium	9	.35 low
Nontreatment	6.29	8.19	.51 medium	8.33	.08 very low

Table 3

Average Normalized Gains from Pre to Mid to Post- Short Answer Assessment, Treatment (N=17), Nontreatment (N=27)

Group	Pre-Average Score	Mid-Average Score	Average Gain (pre to mid)	Post-Average Score	Average Gain (mid to post)
Treatment	4.41	7.41	.65 medium-high	7.71	.25 low
Nontreatment	3.37	7.03	.65 medium-high	7.37	.17 low

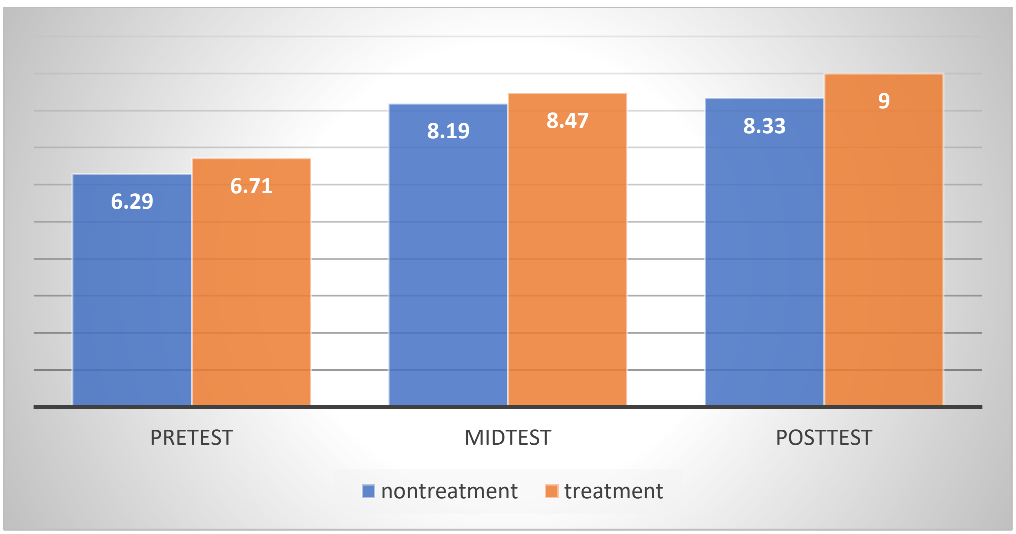

Figure 5. Average score out of 10 points on multiple choice pre-, mid-, and post-test questions, treatment *(N*=17*)*, nontreatment *(N*=27*).*

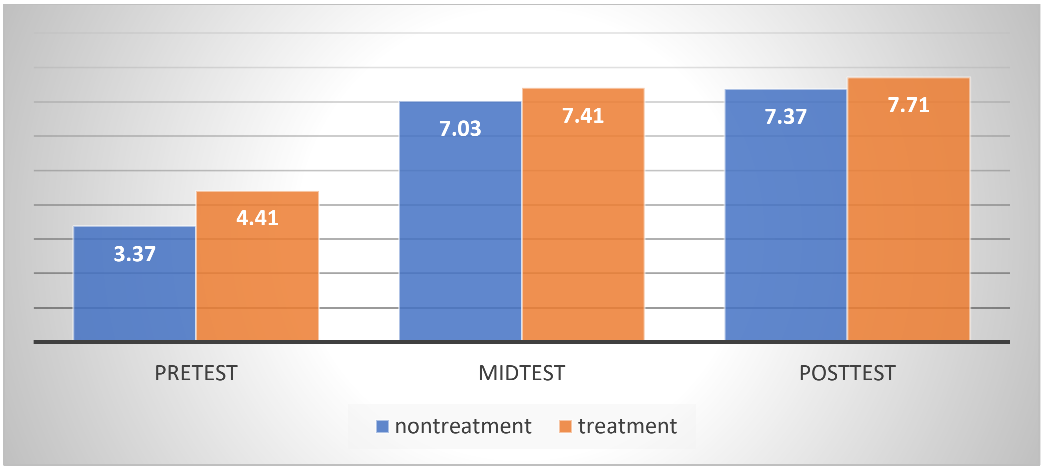

Figure 6. Average score out of 9 points on short answer pre-, mid-, and post-test questions, treatment *(N*=17*)*, nontreatment *(N* =27).

The average scores from the Security System Design Rubric (Figure 7) indicated higher scores on the Security Design Rubric in the treatment group. Five out of 100 points in the Security Design Rubric were allotted to the success of the security system design. Only one team out of seven in the nontreatment group successfully built a security system with six mirrors and with no angles measured. The treatment groups had three out of five successful teams with one team with five mirrors, one team with four mirrors, and one team with three mirrors in the design. All teams in the treatment group made attempts to measure angles in the design process, yet only two groups (40%) included the angles in the drawings. All students were required to draw sketches before the design process and after the design process. The sketches were drawn on graph paper, showing only slight variation in drawings for both the treatment and nontreatment group. Most drawings were not drawn to scale in both the treatment and nontreatment group.

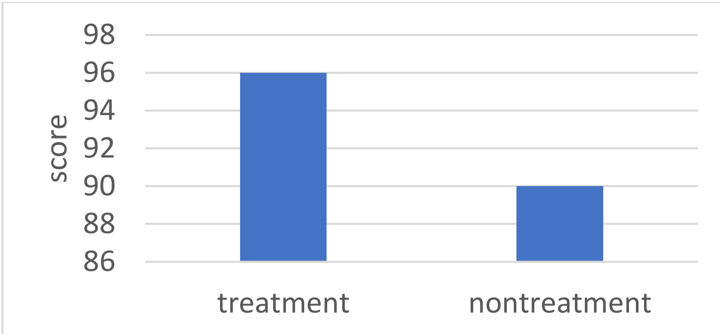

Figure 7. Average score out of 100 points on Security Design Rubric, treatment *(N*=17*)*, nontreatment, *(N*=27).

To determine students' attitude toward problem solving, the students were administered the Attitudes and Approaches to Problem Solving Survey in September prior to any instructions with engineering practices. The test was scored using a Likert scale with the responses Strongly Agree, Somewhat Agree, Neutral or Don't Know, Disagree Somewhat, or Strongly Disagree. Responses indicating a twenty percent change in the agreement of attitude scores are shown in Table 4 for the treatment group. Changes in attitudes included multiple pathways to problem solving, applying scientific concepts to problem solving, drawing diagrams to describe the design process and using data to improve a model or design.

Table 4
Treatment Group Indicating Greater Than 20% Change in Agreement for Attitude Survey (Pre- and Post-treatment) (*N*=17)

Questions	Percent (pre)	Percent (post)
3. There is usually only one correct way to solve a given problem in science.	35%	12%
4. If I am not sure about the correct approach to solving a problem, I will reflect upon science concepts or principles that may apply and see if they produce a reasonable solution.	42%	71%
5. When solving science problems, I often find it useful to first draw a picture or a diagram of the situations described in the problems.	35%	65%
12. I use my data to improve my model or design to make it better.	53%	76%

The nontreatment group participated in the Attitudes and Approaches to Problem Solving Survey in the fall and the spring. Responses indicating a twenty percent change in the agreement of attitude scores are shown in Table 5 for the nontreatment group. Changes in attitudes included using mathematics in the design process, multiple pathways to problem solving, applying scientific concepts to problem solving, drawing diagrams to describe the design process and using data to improve a model or design. More students in the nontreatment group increased interest in engineering projects.

Table 5
Nontreatment Group Indicating Greater Than 20% Change in Agreement for Attitude Survey (Pre- and Post-treatment)) (*N*=27)

Questions	Percent (pre)	Percent (post)
2. In solving problems in science, being able to handle mathematics is the most important part of the process.	37%	59%
3. There is usually only one correct way to solve a given problem in science.	41%	21%
9. When solving engineering problems, I try to develop many possible solutions rather than one attempt.	44%	78%
10. When designing a project, I often make sketches of my design.	48%	74%
12. I use my data to improve my model or design to make it better.	56%	78%
13. I am interested in designing, creating, and building machines and devices (engineering).	4%	50%

Upon completion of the groups' presentations, the groups were asked to complete a reflection component. Students were asked to provide feedback in regard to teamwork and collaboration. One student stated, "I feel we worked well as a group because when one had doubt or trouble, the others helped and tried again. As one of us held the laser the other others maneuvered the mirrors." Another student felt "The teamwork was great. We all helped each other with angling the mirrors. We told each other when everything lined up. Overall, we worked great with each other." Additionally shared by a student, "As a group we had our good days and bad. We spent a lot of time compensating for the improperly positioned mirrors. Sadly, we never created a permanent fix. We wanted a complicated, elaborate set-up, but with so many roadblocks, we went with a simpler, table-level solution. We were used to failure so we rejoiced when we just hit all of our mirrors." Students elaborated how they set up individual roles and duties in their groups, "We had certain jobs like tape, mirrors, laser, and angles." Some students included positive interactions stating “We always gave positive feedback to others when ideas were said.”

In addition, I asked the students to consider how they persevered during their struggles through the engineering process. The instructional coach commented that when one student was frustrated, another student often stepped up to help out the group to promote success. Not all groups were successful or experienced the same level of commitment to the project. Some students indicated which partner may not have worked to his/her potential, may have been on the phone, or talking to other teams in the room.

During the interview questions, students indicated that “I learn more things about real-life in science.” When asked what activities helped you the most, ninety-five percent of the students (N=44) indicated that they preferred hands-on activities as a method of learning of which 18% of those surveyed specified engineering as a preferred method of learning. Due to the open-ended question, students may not have distinguished a difference between engineering and hands-on activities. One student announced that “I have a greater appreciation of what an engineer does. I never want to be one, but I can respect them more now.” Another student stated, “Engineers do a lot more things than I thought they did when I came into eighth grade.” In the interview, one student stated “My group had great discussions so helped me understand things I don’t get.” The same student claimed, “I love engineering, but the laser project made me love it more.”

The instructional coach provided supportive details. She wrote down several quotes from the students, including the instructor comments. The coach wrote down some student frustrations and the responses to each other with the team including, “Why (is the sensor going off)?! It’s on it! The more mirrors it hits, the more it spreads.”

Another student, frustrated asked, “What are we doing?” The coach asked if the students were “Giving up.” The student stated, “No. Not an option. Why don’t we start from the bottom again? That’s where we got the farthest before.” (Deep breaths) The coach noted when I suggested, “Look at the way they have their tape – how is it different from yours?” The student dialogue reflected varied levels of student engagement.

INTERPRETATION AND CONCLUSION

The goal of this action research was to increase awareness of the design process for the students. Another goal was to determine if computational thinking or mathematics impacts the design process. Numerous quantitative and qualitative data collection methods were employed. From the pre-, mid- and post content assessment, attitude survey, student reflections, instructional coach observations, interviews, or presentation of project, the students’ ideas transformed throughout the course of the unit and the year in their science class. Students expressed a greater appreciation for the field of engineering.

The normalized gain in the Properties of Visible Light Assessments reflected medium growth prior to the start of the unit and low normalized gains from the mid- to post- assessments, although more growth was indicated in the short answer responses. The familiarity with the test may have posed a gain in the multiple choice or short answer responses. Students stated that they struggled more with short answer responses questions than multiple choice questions, suggesting that they preferred multiple choice questions.

A disruption in the unit due to weather, eight snow days with an additional eight early out or late start days, disrupted the flow of the unit.

The implementation of data in the treatment group frustrated some individuals, but overall, the students produced better working designs as compared to students not using computational thinking or mathematics, specifically the angle of incidence and reflection, in the design process. The students from both the treatment group and nontreatment group indicated that using data was an important factor in the design process.

Students shifted their attitude in problem solving signifying that there was more than one way to solve a problem. Students also suggested that they were more apt to reflect upon scientific principles to help them approach a reasonable solution when solving a problem. Drawing diagrams to help describe a problem diagrams, the students began adding more sketches to describe the design process. Students realized that many possible solutions should be developed versus one attempt. Students used data to drive their decision making in producing a model or prototype of their design.

I was amazed by the students in the nontreatment group emphasizing the significance of mathematics in problem solving – particularly when I did not require them to partake in the data collection and measurements. I was pleasantly surprised by the number of students that valued the design process and collaborated well to meet their objective.

The post unit reflections and the interview questions were the most insightful evidence in the study. Students understood that working through the problem and their interactions were most beneficial. Most students indicated that they enjoyed working with others. While some students realized that motivating team members at times could be difficult, most enjoyed the collaboration and ability to share ideas in the problem-solving process.

I was hoping more students from the treatment group would like engineering more. Even though students indicated knowledge of the angle of incidence and angle of reflection, the application of the angles to the mirror was difficult for the students to grasp. The treatment group stated that taking time to measure slowed them down and forced them to think through the process more carefully.

VALUE

I have taught various subjects in the last 26 years, mostly at the high school level. In 2013, I enrolled in a mechanics modeling instruction workshop. The training completely transformed my outlook towards teaching. Invigorated, I saw students successfully comprehend demanding material when presented differently. As I incorporated modeling instruction into my own curriculum, I noticed that students wanted authentic problem-solving learning opportunities. I developed projects such as building trebuchets for apples and a yearly cardboard boat regatta. I noticed that the students were completing the project but did not rely upon the scientific process or data in the design process. I began requiring students to incorporate more drawings and iterations in their designs. Employing the design process, I asked students to design a cell phone case and we tested the case at various heights in a high school physics class. After the completion the cell phone project, I noticed the strong similarities between modeling instruction and the engineering process.

This past year I was reassigned to add more rigor in the middle school program, I looked for ways to incorporate the design process while adhering to a mandated curriculum. The engineering component did not require any building, only drawings. Therefore, I began researching ways to add authentic engineering activities into the curriculum. I found a project via Teach Engineering on building a security system.

After researching a security system project, I looked up the costs and tried to order a photoreceptor for the lasers. Instead, I found a Do-It-Yourself video on YouTube, and researched methods to construct my own photoreceptor. I had the bread boards and most of the components in either my storage closet, or the Project Lead the Way teachers had components they were not using. After studying the schematic diagram with my brother, a mechanical engineer, we assembled our photoreceptor. I then ordered the parts to assemble more. One of the greatest successes that I had was the ability to design and assemble the photoreceptors. I started early in January and finished with assembly in February. The process was time-consuming, a struggle, exhilarating, and exactly what I wanted my students to experience. Although I did not want them to spend an inordinate amount of time on a project, I wanted them to appreciate the various stages of problem solving that goes into the design process.

In the future, I would like to work with Project Lead the Way teachers or a physics teacher to ask high students to build the bread boards. There are many opportunities for cross-curricular and grade-level collaborations. This action research provides data to show the value of engineering projects with students and can provide data for some colleagues who are reluctant to add math into engineering projects.

The students had to repeat the design process several times and were required to learn from their mistakes. I tried to eliminate the stigma associated with failure, noting that failure was an important part of the problem-solving process. There was no single answer in the students' product, and multiple solutions could result from a single problem. The students were forced to think critically, collaborate, and communicate their ideas. Particularly important was the respect of each other and individual ideas.

Most of the students were able to work beyond their frustrations and develop resilience. I wanted them to metacognitively focus on their strengths and weaknesses as an individual and team member. The students were open, honest and very reflective in regard to their opinions and thought processes. Some students were able to make connections and relate the content to real world applications. Students also gained appreciations of various career paths.

In addition to asking the students to become more reflective in their learning, I also became more reflective in my teaching. In my own exploration of instructional strategies to provide meaningful instruction that students could relate to, I hoped to share my passion for learning. I realized the importance of data collection and using the data facilitate growth with my students and colleagues.

Working on this project opened up doors for me in the next year. By adding engineering, I looked for opportunities to continue to transform my teaching and learning. This summer I am working as an extern in a local manufacturing industry. The goal is to share experiences with my students to prepare them for post-secondary options -whether the career path is in engineering or a trade. I am able to work closely with the general plant manager, meet with every department in the plant, participate in upper management meetings, ask questions, assist with efficiency within a given project, and then I will get to share those experiences with my students and colleagues. One former student, an engineer at the manufacturing facility, explained that resilience is one of the primary qualities needed in STEM jobs and manufacturing.

In addition, I will be forming a partnership with local engineers as part of a STEM Innovator grant through the state of Iowa. After training, another teacher and I hope to train the engineers to complete activities with our students. Next January I will be in Finland collaborating with Finnish educators and studying STEM and entrepreneurial activities for students in Finland. The engineering activities have not only opened up possibilities for me, the design process has ignited my own personal interest to creatively construct activities that enable challenging growth opportunities for all stakeholders, including students, community members, and educators.

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APPENDICES

APPENDIX A

INSTRUCTIONAL REVIEW BOARD EXEMPTION

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

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Chair: Mark Quinn
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MEMORANDUM

....

TO: Pamela Joslyn and John Graves

FROM: Mark Quinn *Mark Quinn CJ*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: December 1, 2017

RE: *"The Effects of Increasing Quantitative Data in the Design Process in an AP Physics Class"* [PJ120117-EX]

The above research, described in your submission of December 1, 2017, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

_X_ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

___ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

___ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

___ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

___ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

Exemption Regarding Informed Consent

I, Jared Smith, Principal of Muscatine High School, verify that the classroom research conducted by Pamela Joslyn is in accordance with established or commonly accepted educational settings involving normal educational practices. To maintain the established culture of our school and not cause disruption to our school climate, I have granted an exemption to Pamela Joslyn regarding informed consent.

____
(Signed Name)

Jared R Smith
____
(Printed Name)

11/7/16
____
(Date)

APPENDIX B

ATTITUDES AND APPROACHES TO PROBLEM SOLVING SURVEY

Attitudes and Approaches to Problem Solving Survey
(PARTICIPATION IS VOLUNTARY)

To what extent do you agree with each of the following statements when you solve problems? Answer with a single letter as follows:

A) Strongly Agree
B) Agree Somewhat
C) Neutral or Don't Know
D) Disagree Somewhat
E) Strongly Disagree

1. When solving science problems, I often try to relate the problem to my own world.

2. In solving problems in science, being able to handle the mathematics is the most important part of the process.

3. There is usually only one correct way to solve a given problem in science.

4. If I am not sure about the correct approach to solving a problem, I will reflect upon science concepts or principles that may apply and see if they produce a reasonable solution.

5. When solving science problems, I often find it useful to first draw a picture or a diagram of the situations described in the problems.

6. When answering conceptual science questions, I mostly use my “gut" feeling rather than using the physics principles I usually think about when solving quantitative problems.

7. When presented with an engineering problem, I immediately identify the problem and think about my constraints.

8. Often when I am working on an engineering project, I first research the problem to define a solution.

9. When solving engineering problems, I try to develop many possible solutions rather than one attempt.

10. When designing a project, I often make drawing or sketches of my design.

11. When I first test my prototype, I use my data to drive my decision making.

12. I use my data to improve my model or design to make it better.

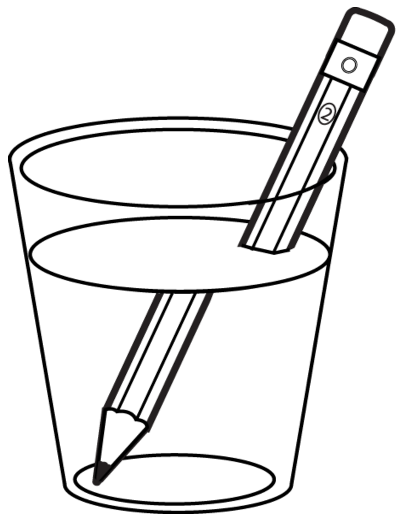
13. I am interested in designing, creating, and building machines and devices (engineering).

APPENDIX C

PROPERTIES OF VISIBLE LIGHT MULTIPLE-CHOICE ASSESSMENT

Properties of Visible Light Multiple-Choice Assessment

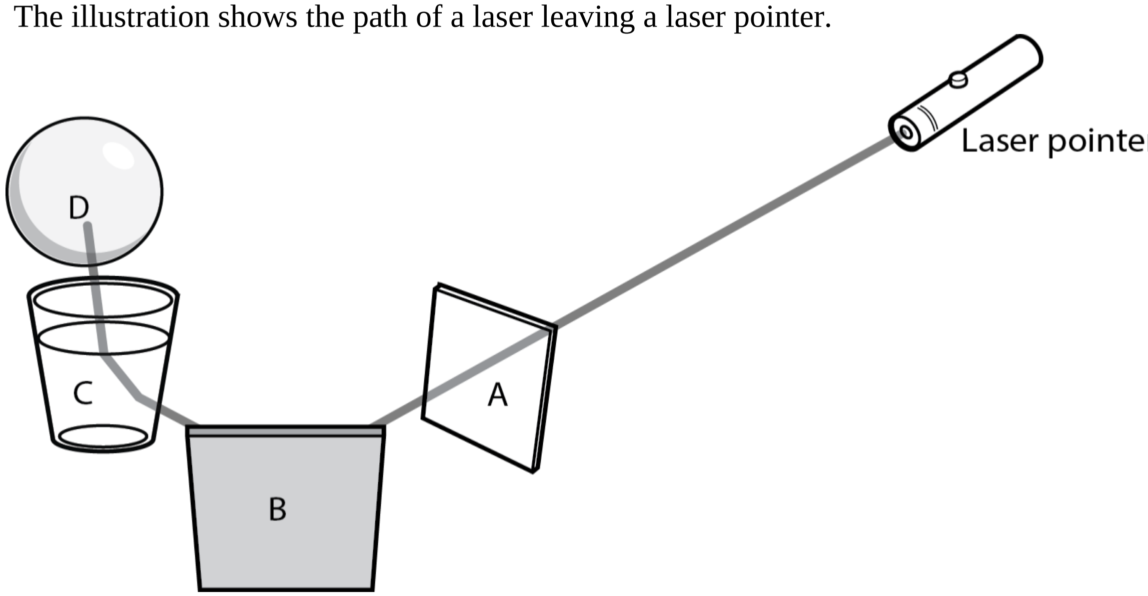
1. A student places a pencil in a glass of water and observes that the pencil appears to be broken.



Which of these provides the best explanation for why the pencil appears broken?

A. The pencil absorbs all the light rays that hit it.
B. Water reflects light rays away from the pencil.
C. Light rays are bent by the water in the glass.
D. The surface of the water reflects light rays.

2. The illustration shows the path of a laser leaving a laser pointer.



At what point is light being absorbed? (circle one)

A B C D

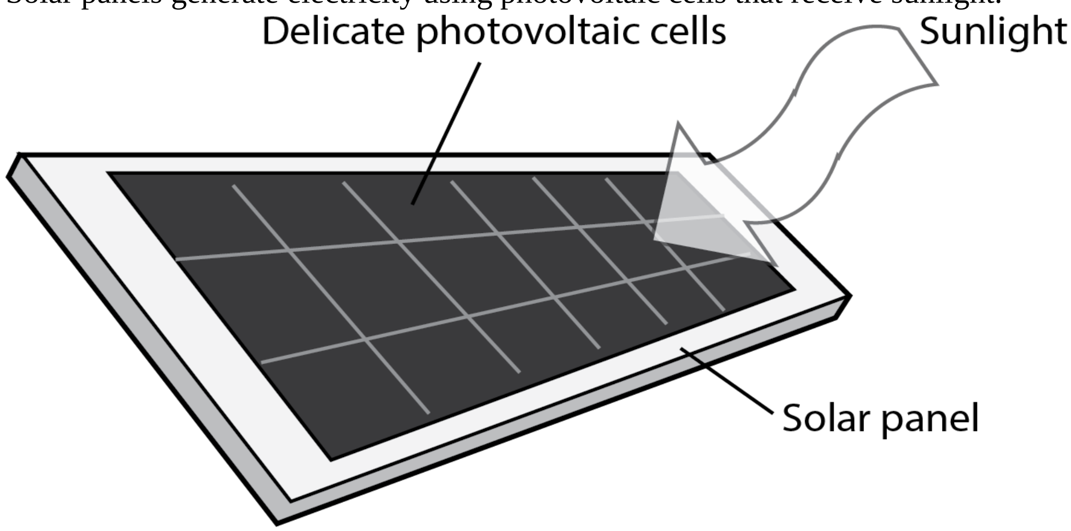
3. The distance from Earth to the moon can be accurately calculated by pointing high-powered lasers onto the moon's surface. The time it takes for the light to return is used to find the distance. To make this possible, astronauts on the Apollo 11 moon mission had to place a device on the moon that would–

A. Store the laser light for future use.
B. Bounce the laser light back to Earth.
C. Allow the laser light to pass through.
D. Change the frequency of the laser light.

4. Which of the following is the best example of an object absorbing light?

A. A black sweater in the sun
B. A clean window in the sun
C. A curved mirror in the sun
D. A long shadow in the sun

5. Solar panels generate electricity using photovoltaic cells that receive sunlight.



To protect these cells from moisture while allowing sunlight to pass through, engineers must design a cover for the solar panel that is-

A. waterproof and transmits light.
B. very flexible and reflects light.
C. stronger than steel and bends light.
D. cold to the touch and absorbs light

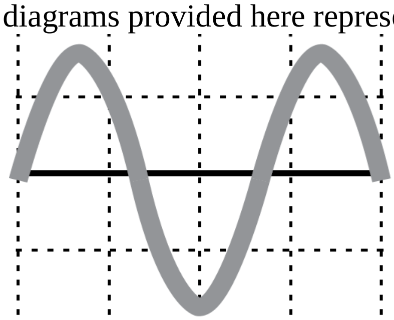
6. Humans see different colors because our eyes are responding to light that is different in which characteristic?

1. Speed
2. Amplitude
3. Angle
4. Wavelength

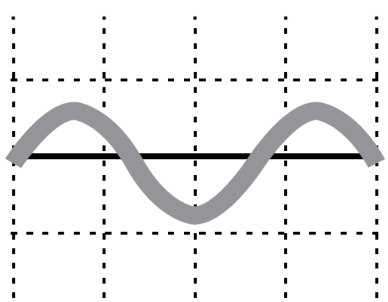
7. A rainbow happens when sunlight passes through water droplets in the air. Which of the following best explains why?

A. Water droplets of different sizes filter out light of different colors.
B. Different chemicals in the water get energy and give off light of different colors.
C. Light of different colors travels at different speeds through different-sized water droplets.
D. Light of different wavelengths is bent at different angles.

8. The diagrams provided here represent two light waves.



Light Wave #1

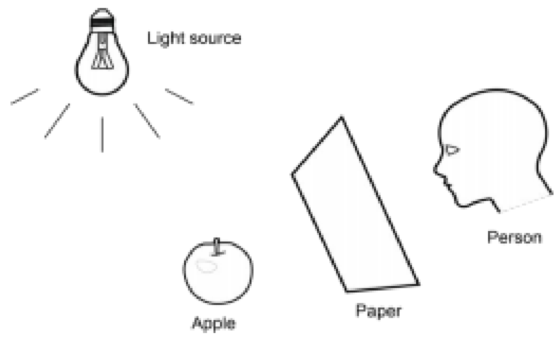


Light Wave #2

Which conclusion is supported by the data provided in the diagrams?

A. Light Wave #1 will appear brighter than Light Wave #2.
B. Light Wave #1 will be a different color than Light Wave #2.
C. Light Wave #1 will reflect more easily than Light Wave #2.
D. Light Wave #1 will travel in a straight line, but not Light Wave #2.

9. The diagram shows the relative positions of a light source, apple, paper, and person.



The person can't see the apple. Which of the following correctly describes the light interactions taking place in the diagram?

A. Light is absorbed by, not transmitted through, the paper.
B. Light is reflected off the apple, but absorbed by the light source.
C. Light from the light source is reflected only off the apple.
D. Light is transmitted through the paper and then reflected off the apple.

10. The idea that light is not matter is supported by which of the following evidence?

A. Light bounces off most objects.
B. Light can be separated into colors.
C. Light can be absorbed by objects.
D. Light does not have mass or volume.

APPENDIX D

PROPERTIES OF VISIBLE LIGHT SHORT ANSWER ASSESSMENT

Properties of Visible Light Short Answer Assessment

1. How do the wavelengths and frequencies of colors change when moving from red to violet through the visible light spectrum?

2. How are electromagnetic waves different from sound or water waves?

3. What causes the different colors of visible light?

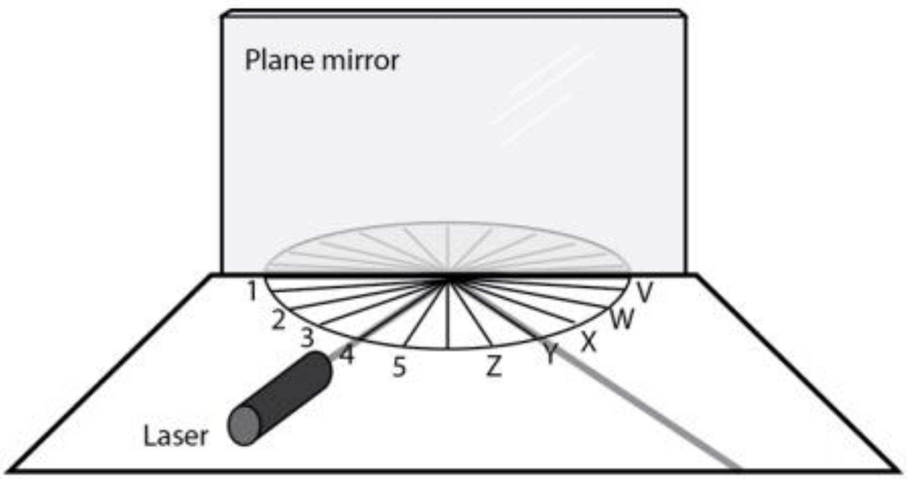
4. List all of the possibilities that can happen to light when it shines on an object:

1.____

2.____

3.____

5. A laser beam is pointed into a plane mirror using the setup shown in the diagram below. Describe how the light would behave if the laser beam entered along line 1.


Plane mirror
1
2
3
4
5
Z
Y
X
W
V
Laser

APPENDIX E

RAINBOW PRECONCEPTION PROBE

Rainbow Preconception Probe

Respond to the following students Maria, Sam and Peyton with your own ideas:

Maria: Sunlight makes a rainbow, but I do not know how light reaches us from the sun. Sound cannot travel through space, so how does light travel through space?

Sam: Rainbows have many different colors, but the light from the sun is only one color. When light travels through water droplets, rainbows form, but I do not understand why.

Peyton: When light passes through glass or crystal, something similar to a rainbow happens. Maybe there is something in the glass that allows us to see all colors just like the grass is green.

APPENDIX F

SECURITY SYSTEM DESIGN PRESENTATION RUBRIC

Security System Design Presentation Rubric

	Score	Max Score
Individual Scores (40%)		
Understanding Lights and Lasers		
Roles of lasers in security systems		10
Understanding of light properties		10
Understanding of laser properties		10
Individual Participation Score		10
Group Score (60%)		
Security System Design		
Laser Selection		5
Explanation of laser selection		10
Limitation of design		5
Safety concerns		5
Explanation of Complete Design Procedure		
Completion (including pictures throughout)		10
Accuracy		5
Estimate of time of construction and cost		5
Presentation		
Organization		5
Creativity		5
Clarity		5
Total		100
Comments		
Group Members:		

APPENDIX G

IMAGE OF STUDENTS MEASURING ANGLES

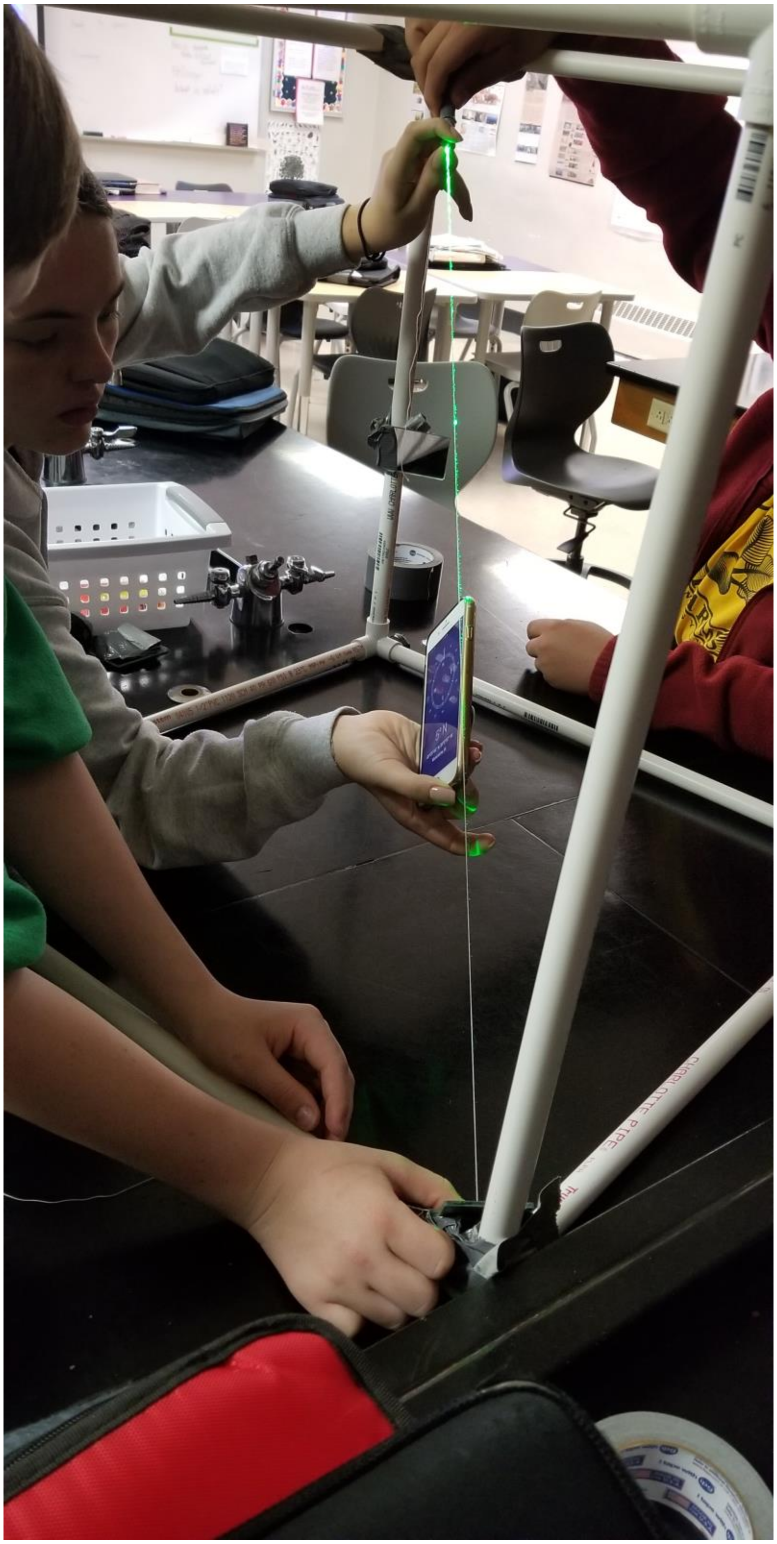


Figure 8. Students measuring angles of lasers lights reflecting off of mirrors.

APPENDIX H

SECURITY SYSTEM INTERVIEW QUESTIONS

Security System Interview Questions
Survey is voluntary

1. What motivates you to learn new concepts in science? Explain

2. Do you try to apply science concepts learned in class to your world around you? Explain.

3. Do you look forward to coming to class and completing lab activities? Explain.

4. Do you look forward to coming to class and completing white boarding (explaining homework)? Explain.

5. What kind of lab activities makes learning more interesting? Explain.

6. Have you engaged more with your peers this unit? Explain.

7. Did you feel you could personally relate to the energy concepts in the energy concepts this unit? Explain.

8. Did this connection motivate you to learn? Explain.

9. Did the lab activities and assignments help you to understand the concepts and ideas better? Explain.
   a. What activities helped you the most and why?

   b. What activities helped you the least and why?

10. Did the class activities, labs and assignments help prepare you for the unit test?
    a. MC questions?

    b. FRQ?

    Explain.

11. Can you explain how your group discussion affected your understanding?

12. How has your view of engineering changed as a result of completing this project?

APPENDIX I

SECURITY SYSTEM REFLECTION QUESTIONS

Security System Reflection Questions

1. Did you save your troll?

2. How many mirrors were used?

3. Did you measure your angle of incidence?

4. If the angle of incidence was measured, what was angle?

5. Did measuring the angles help you?

6. How well did your team work/collaborate together?

7. What did you do to overcome your frustrations or obstacles?

8. How did your design change?

APPENDIX J

INSTRUCTIONAL COACH OBSERVATIONS: NONTREATMENT GROUP

Instructional Coach Notes/Observations/Quotes from Nontreatment Group

- “We started with a plan and then we changed it 5 times - we couldn’t get the laser to hit the right angle”
- “Why are you doing it that way?” “Just trust me…”
  (Using paper to see where laser is pointing - adjusting mirrors) “Where do we need to put the sensor & troll?”
- “How is it going?” “Not good - we have to restart. We need plan to keep the mirrors stable. “What angle is it supposed to be at?” “I don’t know, I just tip it down.”
- “Human error - need the laser to stay still, but every time we have to move the frame, we have to readjust the mirrors.” (use helium laser w/stabilizer)
  (Randomly pointed the laser & saw where it was pointing next) “It depends on the angle of the laser, not the angle of the mirrors.” “I hate this!” “What if we don’t secure this until we get all the mirrors in place? There’s so many ways it could go!”
- “We’re trying to get the laser to go up and then back down without going through the center.”
- “Hopefully this doesn’t touch the troll because if it does, I am done.”
  “You missed it by an inch - quick, grab your book!”
- “We’re trying hard, but it’s hard because they keep changing.”
- “It hits it, its just minor movements with my hand that moves it.” T. response: Play around with it until you get it. Frustration point right at the finish line.
- “Why (is the sensor going off)?! It’s on it! The more mirrors it hits, the more it spreads.”
- “What are we doing?” “Giving up.” “No. Not an option. Why don’t we start from the bottom again? That’s where we got the farthest before.”
  (Deep breaths)
- T. response: Look at the way they have put their tape - how is it different from yours? What might be more stable?

APPENDIX K

INSTRUCTIONAL COACH OBSERVATIONS: TREATMENT GROUP

Instructional Coach Notes/Observations/Quotes from Treatment group

- (Experiment with different positions, then measured the angles.)
  "Ok, we're just going to take this one down, then start over."
  "Instead of that, why don't we just tape it up like you did here."
  "If we have even just one that's not at the exact right angle, it's not going to work."
  "But we can do it, just keep going." *Positive self-talk
- (Laser pointing all the way around the perimeter) "We thought it would be easier for anyone reaching in from any side."
- (Laser on top corner) "We felt like if someone were reaching in, it would be more likely to trip the sensor."
- (Random placement of laser?) "We just wanted it to hit right here. I don't know why."
- "This doesn't work. That is big bad." "Great, now what?" "I don't know why it's not working. Maybe it's just the mirror. I'd say it's the laser, but I don't what to mess with that. We had it, but we can't get the sensor to work."
- "Yours is wiggling because you're using the wrong hands. If you can get it at the right angle, we won't have to hold it." "Is it connected?" "It's on it right now." "We lost it." "C'mon guys, we got this." *Positive self-talk
  "Bubble wrap? Well, because it's fun. And I'll stick it under here to prop it up."
- "Maybe we should turn that mirror sideways so it hits this mirror here - we'll have more room here." "Help! No, not that… the mirror! Tape!" "I'm so confused, why is it not.." "I need more tape!" *Having to explain thought-process to group members
- "Now it's totally messed up. Is there a ghost?" "Ok. Just hold it there." "I'm just gonna wait for it to move…"
- "Need your help, chief. Tape." *methodically going mirror by mirror (random?)
- T. As you get to your 6th mirror - can minimize the spread of the light by making sure your mirrors are cleaned and your laser is centered on the mirror. It's easy to get frustrated, the goal is to test on Friday.
- "Are we going to put a mirror here or here?" "What if we go from here to here?" "But the troll is here. Why would we want a mirror when they could just reach in through here?" "Does it need to be in the center or can we put it anywhere inside the frame?"
- "I need to test it with each mirror." "Do we still need to get the angles?" "Yeah, we do."
- "We took one mirror off so that the light doesn't spread out as much and will hit the sensor." "As soon as you're done with your tape, I'm going to add tape to this one." "We still need to get our angles." "We had it, then we moved."
- (4 mirrors total, 2 on opposing posts, adjusting 1st mirror so that it's higher up and the laser will point directly in the center. Plan to add 2 more mirrors on the opposite posts.)
- (Testing each mirror, on the 5th) "Try to get it off the edge of the mirror. We're hoping to still get to 6."
- "We had 6 mirrors yesterday and the laser was right on the sensor, but we think it dispersed too much, so we've got to work with 5." "It's not going to work… it's been brighter and not worked before." "It's going to work! It's just the sensor." "It's on there all the way - I wish these were more sensitive. The light just spreads out too much." "It is actually working. Are we going to have to use one less mirror?" "I hope not…" "We have it perfect right now. You can't get it any brighter than that." "Did you wash all the mirrors? Try the green light from that point."

*Many groups have given up on finding angles at this point. Why? Focused on making it work and then finding the measurements later?

Test: and evaluate prototype

- "We're trying to get our 5th mirror. Do we need to get it that high or can we put it right above the troll's head?"
- (Have all 6 mirrors) "We're trying to stabilize laser and reset so they're all lined up. We tested it with the other laser and it worked." "They are all in the right spot. They are all clean. Maybe it's the laser?"
- "So, it's ok if we don't have 6?" Move backwards! "It worked with 4, Do we go with 4 or try for 5?"
- (Have 3 mirrors) "Where will you put the troll?" (It works! Moving on to reflection)
- "We weren't far from our original design. We went from 5 mirrors to 3, but they're still in similar spots." How were the angles helpful or not? Did it slow you down? "I didn't really know what to do with them." "They slowed us down. It was frustrating but also helpful. It got us where we needed to be, but it took a lot of time."
- (Have 5 mirrors, trying to reset the mirrors so they hit the sensor) Go back to 3. See if you can get it at 3. "How about we stabilize that one?" "Woohoo!"