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A Teacher's Journey Integrating Engineering in a Middle School Science Classroom and the Effects on Student Attitudes (RTP)

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Abstract

As teachers are encouraged to help students become problem solvers, incorporating engineering methods into the classroom has become an important theme of conversation. The purpose of this paper is to explore the change in student attitudes when integrating engineering instruction within a middle school science classroom. This study involves 8th grade students located within a single science teacher's classroom exploring the integration of engineering activities and content for the first time. We assessed student attitudes using a survey constructed by the Friday Institute[1] aimed measuring perception toward STEM related fields and study. Surveys were administered before and after engineering lessons.

Along with student perceptions toward STEM content, we will describe the journey and thought process throughout the 8-week period from the implementing teacher's point of view. We will detail the implementation process, reflect on student success and struggles, describe perceptions of student achievement based on student responses and completed work, as well as present an overarching reflection on the author's journey throughout the process. Through the study and reflection others can learn how to bring engineering design into the classroom. It is also our goal that this process and study, including implementation, will help teachers become more confident adding engineering into their common practices and aid them in finding a place to begin.

Introduction

Science, technology, engineering, and math (STEM) education is a national trend to prepare the nations' youth for competition in the global economy. STEM is being discussed from the national level down to individual school buildings as schools begin to implement the Next Generation Science Standards (NGSS)[2], in accordance with the Common Core English and Math standards[3]. Science, mathematics, and technology have national standards that support various learning objectives but what about engineering? The Committee on Standards for K-12 Engineering Education[4] has concluded that there isn't a significant population of teachers qualified to teach engineering and experience is limited. As found by Lachapelle, Cunningham, & Lindgre-Streicher[5], "many teachers hold misconceptions about the work of engineers". If teachers are unprepared and lack the understanding of what engineering is then they are unable to effectively teach it. Along with engineering knowledge, all students benefit from the ability to solve problems and to practice that skill in a controlled setting. Basham et al. [6] believe access to STEM education for all students is essential for national success and that "all students, including those with disabilities and other diverse learning needs, should be included in meaningful STEM education and develop expertise in STEM areas as well as 21st century skills associated with STEM learning." The National Research Council[7] explains that high-level STEM instruction is an exception and that " further transformation is needed at the national, state and local levels." For this to be the case teachers must learn how to integrate and adapt to the current needs of our nation. Oliveira et al.[8] suggests that best practice in science education should include relevant and engaging activities, the use of inquiry based learning, differentiated instruction, and collaborative work, all of which can be supported using the engineering design process by allowing students to solve problems rather than just read about them.

This paper explains my journey as a science teacher through my first attempt at integrating the engineering design process in my classroom with the intention of providing others with the guidance to follow suit. I am in my 4th year of teaching science and attending Boise State University for a Master's in STEM Education. The activities discussed grew out of an independent study exploring engineering content and developing lessons incorporating engineering design in the middle school science classroom. A typical instructional classroom year consists of student exploration through energy, forces and motion, introductory chemistry, and chemical reactions using scientific research and the scientific method.

Research Methods

Participants are located within my 8th grade Physical Science classroom in the West Ada School District in Meridian, ID. The school is comprised of 1201 students, 628 of which are male and 573 are female. Of the total population approximately 91% are white, 8% are Hispanic, and 2% are of various ethnicities. Approximately 15.4% of students take part in free and reduced lunch. At a state level, no engineering standards have been implemented and the NGSS[2] are being discussed for future adoption.

I introduced students to the concept of engineering integration within science content and asked them to participate in the data collection regarding their attitudes towards engineering and STEM concepts. I assessed attitudes using a Likert scale survey created by the Friday Institute[1]. The Friday Institute STEM Student survey[1] is designed for students to answer STEM content specific questions gauging student attitudes and confidence. There are a total of 52 questions with a break down of: 8 questions specific to Mathematics, 9 questions regarding Science, 9 questions for Engineering and Technology, 11 focused on 21st Century Skills, 12 questions surrounding interest in various STEM careers, and 3 questions regarding student current progress, possible future advanced classes, and knowing adults in STEM careers. I chose the survey because of the broad range of content it covered as well as the section regarding possible career choices students might be interested in relating to STEM fields. An objective of using this survey aimed at trying to understand if the incorporation of engineering impacted student attitudes toward engineering and science. Due to the nature of how it's constructed, the Friday Institute STEM Student survey[1] is broken down to allow for the assessment in independent subjects.

To ensure confidentiality, students returned their consent forms to another teacher who also kept track of participants, secured information, and administered surveys so that no bias was placed on students by me. Surveys were administered prior to engineering integration and after final engineering lesson, a span of 8 weeks. Just over half the population, 92 students, chose to allow their information to be included in the data collection, however all students participated in class activities and lessons. The survey's construct validity was assessed through exploratory factor analysis and used evidence of content validity through subject matter experts[9]. Reliability was measured using Cronbach's alpha for internal-consistency[9].

Along with survey data, I used reflection as a method of data collection. While students engaged in lessons I wrote notes, observed behaviors, and engaged in discussion to analyze lessons and their benefits toward student learning. My goal in doing so was to reflect on the success of lessons from my perspective and to reflect on student success sometimes hard to see on paper. By incorporating reflection I am able to communicate my struggles and success as well as student behaviors that are important in the learning process.

Lesson Overview

Before deciding on engineering tasks, we (my professor and I) spent a considerable amount of time developing engineering design worksheets to be used by students to guide their engineering projects. We decided that the best way for students to show their individual thinking and group ideas was to break the paper into parts for each task of the engineering design process. The process we constructed to best fit my classroom includes: identifying constraints, creating an individual product or idea, creating and designing a group product, modifications, and a final analysis. It is important for students to be able to individually brainstorm ideas and then bring those individual ideas to a group to complete a common task. Brainstorming allows students to have multiple solutions to a problem and as well as to guide the student toward a place to begin the task [10]. We designed the engineering design worksheets (see Appendix A), so that students first identified constraints before beginning any work. Next, students created an individual product, brainstorming various possibilities to guide thinking about multiple approaches that can be made to improve a design. Then using their individual ideas they created a group idea that included at least one aspect of each person's individual designs. During the process, students included any changes in their original group designs to better reflect the process they followed. The design worksheet includes a section for each modification made for students to record their testing process test as well as their modifications. After the final modifications and testing, students completed an analysis of the project and using guiding questions such as: what went well, what didn't go well, challenges they faced, contribution to group projects, how they would change the product to improve it? The design process stated was created using various parts of different models to best fit the classroom and implemented structure of inquiry as well as to complement the scientific method already taught. Design worksheets were then graded using a rubric created specifically for the engineering process stated. According to Sale[11], rubrics "provide a guiding frame for focusing attention on the key elements/constructs (performance criteria) of the assessment area and summary descriptors of a range of performances". I scored each category of the engineering design process out of 5 with the minimum being 2.5 if they turned in a product, see Appendix B.

Students were introduced to engineering design through a foil boat challenge[12]. I decided on the challenge to create a floating foil boat out of a 12 x 12 inch piece of foil, no bigger than 6x6x6 inches when tested, and used no more than two straws or one straw and a 6 inch piece of painters tape. Before starting, the students completed a design worksheet, which asked them to identify possible constraints of the challenge and draw two pictures of a boat to begin the brainstorm process. After a class discussion regarding how boats float, students individually constructed a boat and tested its ability to float. While creating their products I encouraged students to keep track of any design modifications. Students formed groups of three and design a group boat taking at least one aspect from each individual's successful design. Along with the prior requirements, students now had the challenge to create a design that could hold the most possible pennies. All group designs were drawn on paper before being crafted. As students constructed their designs they recorded any modifications made on individual papers. All groups tested their design and made modifications at least once during the process. After completion of group building and testing the class held a discussion regarding the difference between engineering design and the scientific process. Students identified how they are similar and how they differ. The focus became that the engineering design process is a process that identifies, designs, and redesigns and not experimenting to confirm knowledge.

I decided on an exploration of wind turbines for the second engineering task. Convection currents and renewable energy sources were the topic of study for the unit. I built turbine stands out of PVC piping and KidWind building parts[13]. Students had the task to build a turbine that produced the highest speed measured using a voltmeter. Before building they worked on a design worksheet, which included identifying constraints, drawing and labeling the energy flow through a wind turbine, and brainstorming ideas of variables they could manipulate to maximize the efficiency of their designs. Upon completion, students organized themselves into groups of three or four and began sharing ideas and creating a group design based upon their individual ideas. Students had access to cardboard, corrugated plastic board, painters tape or duct tape to construct blades for their turbines and used a fan to simulate wind. Student's recorded qualitative and quantitative data, along with any modifications made during the test, modify, and retest cycle. I expected students to modify their designs at least once to improve them as much as possible. After testing, students shared their data with the rest of the class to identify successful products.

I decided on a balloon car project for the third task. This activity included collaboration between math and science. The math teacher used student data to introduce correlational graphing and reading graphs. In math, the lesson then extended to speed and acceleration graphs. In science, I used the lesson to support forces and motion. Students had the task to build a car that travelled at least 10 feet, per math request; only using recycled materials and one balloon. At the beginning of the project, students researched Newton's laws of force and motion and balloon car designs. After research and individual designs, students grouped into math appropriate groups and given time to construct their designs. Upon completion of travelling at least 10 feet, students had a redesign task of modifying the cars so that they travelled 10 feet in the greatest amount of time possible. As with previous projects, my expectation included identifying any modifications, by drawing pictures, and explaining the thoughts behind them. The design worksheet included a section for students to draw their final designs and explain how all three of Newton's Laws interacted with their cars and a section for students to calculate speed and acceleration of their cars.

The fourth and final task centered around Newton's Third Law of Action and Reaction. The students designed and built cardboard arcade games, inspired by Caine's Arcade[14] built in California. The class began the lesson by watching the documentary of Caine's Arcade created by Nirvan Mullick[14]. Students were then given the task of researching arcade games that could be built in class out of cardboard boxes. Each class generated a list of games on the board that demonstrated the action/reaction relationship appropriately. Students shortened the list to 8-9 games, by class vote, and formed groups of three to four with one game per group. Classes had access to cardboard, duct tape, painter's tape, hot glue, and any other supplies left from the balloon car project, other required materials were up to students to provide based on their game needs. Game construction took place over four class periods of 45 minutes. After game construction students had the objective to change from the producer role to the consultant role and to provide feedback on a game from another group. The consultants wrote the feedback to be given to the designing group and included: good things about the game, how it could be modified to improve design, future concerns for game play, and where they identified the action/reaction relationship occurring. Consultants gave their feedback to the designers of the game and I provided class time to make modifications. Students set up games on the final day and had the opportunity to play peers designs. As they played they identified the action/reaction for each game, where potential and kinetic energy occurred, and any forms of energy they could identify. Post attitude surveys were administered just before completion of final task.

Survey Results and Discussion

I analyzed the Friday Institutes' surveys[1] using an unpaired t-test in Excel and compared the pre and post class averages. The results of the mean analysis showed negligible differences with a slight negative impact, if any. The engineering mean pre-lessons were 3.67 and post lessons were 3.47 out of 5. All subjects, including careers, followed the same pattern.

In my concern to protect student anonymity, I neglected to develop a method to compare results using a paired t-test. Due to this oversight I was unable to do a statistical analysis of paired data. Overall, the results were slightly unexpected based on the level of engagement I observed while students worked on the projects, as well as the quality of work turned in. I expected that there would be a slight increase in attitudes. There appeared to be some disconnect between student involvement and information collected on the surveys, as well as inconsistencies in some of the students' responses. For example, several students responded that math was hard for them but they knew they could do well in it or that math has been their worst subject but they could get good grades in it. This same trend occurred in science as well. The responses appear to conflict with each other suggesting that students may not have understood the questions or didn't take the time to answer carefully.

Lesson Reflection Discussion

Prior to the implementation of Engineering Design, I had not completed any intentional engineering tasks in the classroom. In years past, I encouraged students to build products under the false pretense of engineering but missed any type of structure and understanding as to what engineering design really entailed.

Before deciding on the foil boat challenge as the first activity I had several ideas that I soon realized supported building and fun instead of supporting content, which was the goal. It became apparent that engineering education isn't just building but rather problem solving on a different level. The mission of finding an introductory lesson that also fit within content objectives took a little time and patience as well as compromise to ensure students could support knowledge development but also be engaged. To begin the lesson students brainstormed how boats float, discussed their ideas, and then sketched two boats that could be made out of foil and straws. Many students resisted sketching two boats because they said they already knew what they wanted to make, which surprised me. I assumed that students would be open to designing more than one idea because it allowed them creativity and freedom to design their products. After the completion of their drawn designs on design worksheets, students began building their boats. All individual boats successfully floated, which appeared to boost confidence for the group challenge. The group challenge appeared to be a bit trickier for students because they had to incorporate at least one design idea from each of their individual boats. All groups were successful in getting their boats to float with at least 3 pennies with a high of 213 pennies. The groups that held more pennies realized during modification that boats with a bowl-type shape could hold the most mass. I was pleasantly surprised to hear the positive language students used no matter how many pennies their boats held. After students completed their analyses, we discussed how the process we followed compared the scientific method. As a class, students suggested that parts of the scientific method were similar to the design process because they had to brainstorm a hypothesis in their heads and draw it to create something that would work, but from there it became a bit muddled. Students suggested that the scientific method looked more like a linear process that brought up a greater number of questions while the engineering method looked more like a cyclical process, so they chose to refer to the engineering design as a design loop. I suggested to students that scientists use the scientific method to answer questions while engineers use the engineering process to solve problems. Students were excited to hear that we would be using the engineering design process in the following lessons, while keeping experiment guidelines in mind as to not change variables inappropriately. If done differently, students would do some pre-research on boats so they could compare and contrast their designs as well as gather information on how boats float. The group design task would also include the consideration as to the purpose of the boat in the context of real life and allow them to choose a boat to hold cargo or passengers.

I became more confident in the engineering design after completion of the foil boat activity. Our next classroom goal was to manipulate wind turbines. Completing the wind task under the umbrella of engineering, instead of scientific method, changed by asking students to create the best product possible using only one variable and modifications, instead of having students test 3 variables like done in past years. Prior to the wind lesson, students engaged in learning about renewable and non-renewable energy types as well as energy flows through various energy sources. Introducing and explaining the design worksheets seemed easier the second time because students had seen them before and appeared better prepared for the task. The lesson went well based on student engagement, participation, and sample such as the example in Figure 1. Although the student identified amount of energy in the sample, since they were just measuring the voltage output of the turbine they really measured speed. Students worked at their pace instead of following a step-by-step guide, with some students working faster. I didn’t expect students to continue following the scientific method. Several groups began to manipulate multiple variables instead of one, when they realized the requirements they seemed to slow down and discuss how to make it better instead of trying to finish it all. During this lesson I realized that the scientific method had become a routine where students appeared to be on autopilot to complete the assignment instead of engaging and questioning their results.

The balloon car activity felt a bit more chaotic due to the complexity of students creating a product in both science and math classes. The math teacher and I structured the environment to be an open classroom concept for students to go where they needed the most help. Many students used wheels constructed from bottle caps or old CDs, while the bodies were created from cardboard products, as shown in Figure 2. The mathematical expectations went well and most groups were successful in creating a car that travelled at least 10 feet. The task of redesigning their cars to travel 10 feet in the greatest time possible wasn't as successful for most groups because they struggled to slow down their cars or added too much mass, which made them unable to move with a balloon. Luckily the task didn't dampen their spirits and they continued to modify until told otherwise. One of the biggest concerns with this activity included the mathematical equations for acceleration because we calculated speed using a stopwatch. I intended for students to use a motion detector but the cars often didn't move in a straight line and students had a hard time figuring out which numbers to record. In the future, I will use photogates to ensure more accurate numbers and to better explain instantaneous versus average speeds. I enjoyed watching student's problem solve and work towards bettering their designs.

We chose the cardboard arcade to help students explore Newton's Third Law and action and reaction relationships. I realized while doing balloon cars that students struggled to comprehend action and reaction forces. Creating and playing cardboard arcade games demonstrated this relationship well, this can be seen in Figure 3, and students enjoyed the task. Arcade research and brainstorming went well and was beneficial to the ideas suggested for the creation of games, as students didn't appear to struggle with generating multiple ideas. After students chose their games they immediately began discussing as a group what they expected to happen and how it should look. By this lesson the design worksheets were a tool they were used to and felt comfortable completing without prompting for further explanation. Students spent four 45-minute class periods constructing and modifying their games. On the fifth day students switched roles from the producer to a consultant and played and evaluated at least one other group's game. Students positively conducted conversations regarding how to improve games and the advice was taken seriously as was observed through modifications made after receiving input. After the modification process they set up their designs around the classroom and played while identifying the scientific concepts. I expected students to be bouncing between games and playing chaotically, however, again they took the assignment seriously. Most groups stayed together and immediately after playing completed the science evaluation. It was surprising but exciting to watch students take pride in their games as well as their peers games. Given more time and space I would have liked to see the reaction to opening all games up to all class periods and letting them play across periods and not just within their own.

Teacher Reflection

When I first began the lesson planning process, I was unsure of how engineering would look in my classroom. The thought of students building various things alongside of science was rich in my mind, however I soon realized that engineering is more than just having students build things. I slowly began to realize that engineering wasn't just having students create a product, but the process of design and redesign is as important as having a problem to solve. I had the notion that incorporating engineering was going to be easy to implement and while it wasn't hard, it took purposeful planning and constant reflection regarding what I wanted my students to accomplish and learn. Students appeared to be more engaged and I saw less off task behavior than in previous units. If students encountered a problem they began to brainstorm solutions themselves instead of asking me for an answer. I no longer provided them information regarding what they needed to do but became another brainstorming mind used to generate ideas. It's empowering to allow students to create their own products and solve their own problems.

I had to adjust to the thought of the engineering design process because it differed from the scientific method. As a science teacher, the scientific method is used almost exclusively when students do experiments or when conducting research. Along with consistent use in the classroom, the same method is taught using identical steps from sixth through eighth grades. Although similar, switching from the scientific method to engineering design took some practice. On multiple occasions while brainstorming lessons, I had to consider the goals I wanted students to accomplish as far as engineering strategies, instead of trying to prove a point or back up previously known content. In addition to personal struggle, several students continued to follow the scientific method even though the process varied from the assignment they were currently participating in. I realized that the scientific method has become a conditioned process instead of a process in which students follow to show comprehension. My students had become accustomed to following a routine instead of questioning design or engaging in content. This discovery has led to more in-depth analysis for current and future lessons regarding the purpose of which process is used and why.

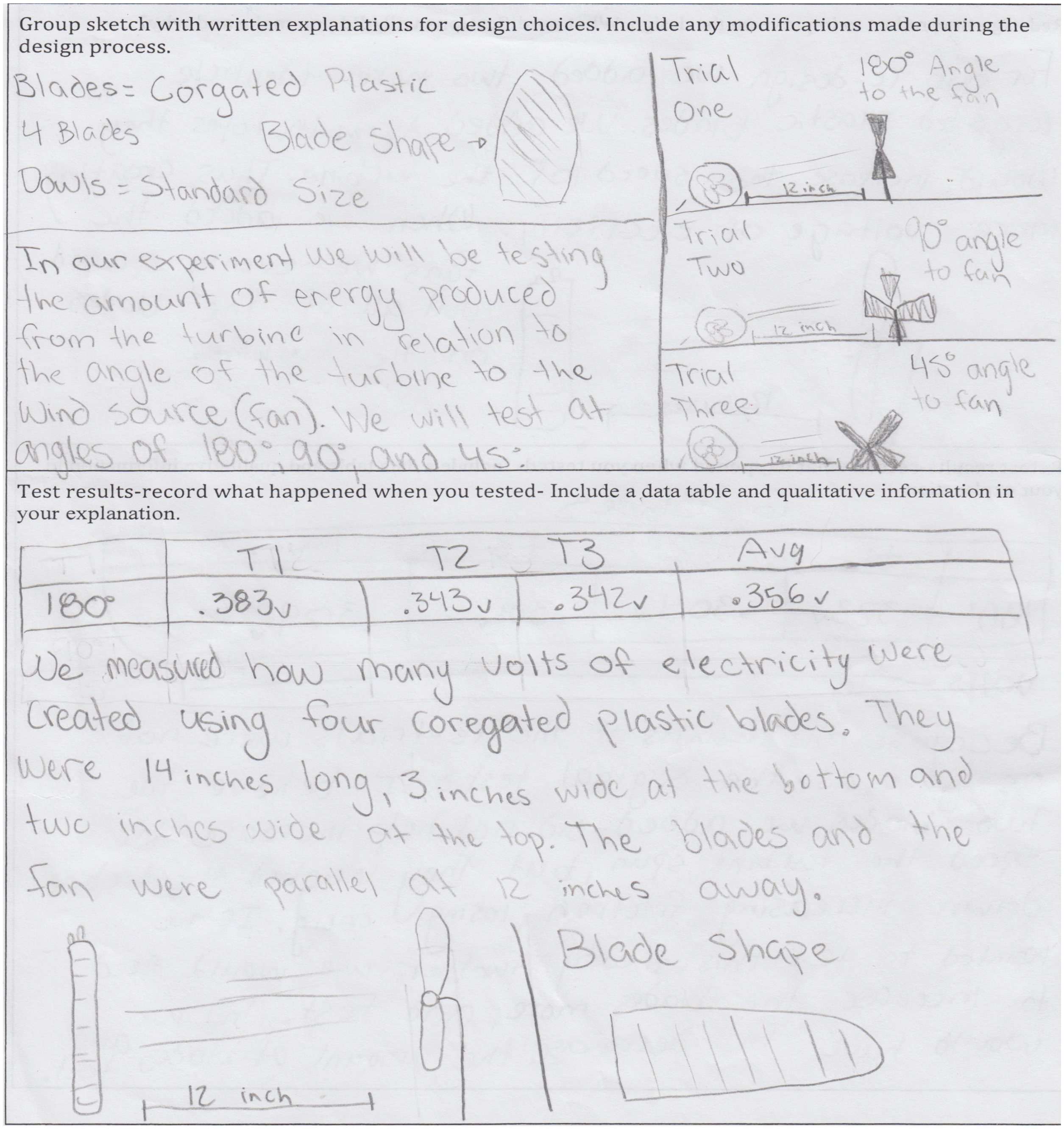
The word 'failure' is defined as the lack of success by Merriam-Webster[15], but over the course of the engineering activities students understood failure as a reason for change instead of the typical notion of not doing well. Students often use the word in context of not doing well in a class or on an assignment, however when it came to the design process they used the word modification instead of failure and weren't so focused on being right but rather on being better. This is an interesting observation because I hear students talking about failing or not doing well on assignments, but when it came to the engineering process I didn't hear it once. Students became comfortable with explaining their ideas for the how's and why's using science instead of worrying about getting things right or the need to be perfect in their work. This has given me more confidence as a teacher to continue using the design method and also the confidence to try new things in teaching. If students feel more confident expressing their ideas without feeling as though they may fail they'll be willing to take risks and try new things.

As a science teacher my goal is to foster a curiosity about the world. After the realization that incorporating engineering wasn't just building things, I had some hesitation about using the design process. The first lesson was primarily design based, but the wind turbine and balloon car lessons were an uncomfortable mixture of engineering design and science. The uncomfortable feeling came from having too much design and not enough science or too much science and not enough design. It wasn't until the cardboard arcade that we found a good balance of science and engineering design. Students appeared to better connect the science and engineering when they designed and explained together instead of working on one thing at a time. By building the lesson so that students explained action and reaction along various points in the process appeared to help foster better understanding as can be seen in Figure 3. Along with learning, students also enjoyed the hands on building as observed by conversations with my students.

Conclusion

Incorporating the engineering design took time and thought but worth the effort. While the surveys didn’t suggest a significant change in student attitudes, I noticed a difference in student behavior and quality of work. Students weren’t just going through the motions of following directions to fulfill a grade, but rather actively participating in and engaged with their education. It took four lessons before finding good balance, however I learned a lot along the way. Doing more than one engineering lesson became extremely beneficial in experiencing the design process for myself. Students are capable of problem solving and peer motivation when given the opportunity to do so without the pressure of being right. Incorporating the engineering design provided great opportunity to explore and reflect on what we ask students to do and why. Doing for the sake of memorization means nothing without context and real application.

I will continue to use the engineering design process in my classroom within the context of physical science. It has helped me reflect on my practices in the classroom and increased confidence in both my students and myself. In order for teachers to be successful in incorporating the engineering design process, we must actively participate in ongoing learning for engineering and science education and be willing to take risks for the benefit of future generations.



Group sketch with written explanations for design choices. Include any modifications made during the design process.

Blades = Corgated Plastic
4 Blades
Blade Shape →
Dowls = Standard Size

Trial One — 180° Angle to the fan — 12 inch

Trial Two — 90° angle to fan — 12 inch

Trial Three — 45° angle to fan

In our experiment we will be testing the amount of energy produced from the turbine in relation to the angle of the turbine to the wind source (fan). We will test at angles of 180°, 90°, and 45°.

Test results-record what happened when you tested- Include a data table and qualitative information in your explanation.

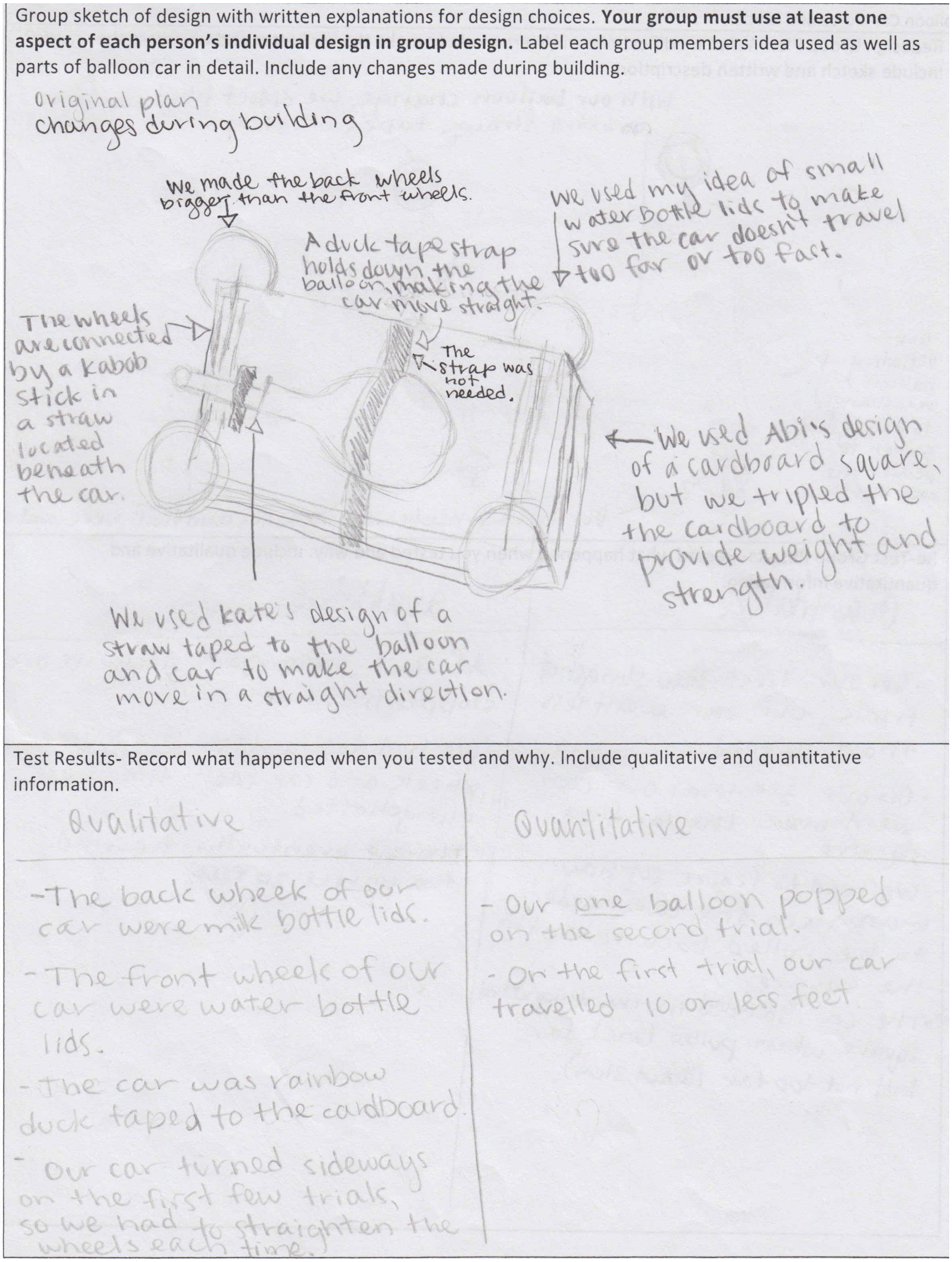
	T1	T2	T3	Avg
180°	.383v	.343v	.342v	.356v

We measured how many volts of electricity were created using four coregated plastic blades. They were 14 inches long, 3 inches wide at the bottom and two inches wide at the top. The blades and the fan were parallel at 12 inches away.

12 inch

Blade Shape

Figure 1. Student work explaining wind turbine activity using engineering design worksheet.



Group sketch of design with written explanations for design choices. **Your group must use at least one aspect of each person's individual design in group design.** Label each group members idea used as well as parts of balloon car in detail. Include any changes made during building.

Original plan
changes during building

We made the back wheels bigger than the front wheels.

A duck tape strap holds down the balloon, making the car move straight.

The strap was not needed.

We used my idea of small water Bottle lids to make sure the car doesn't travel too far or too fast.

The wheels are connected by a kabob stick in a straw located beneath the car.

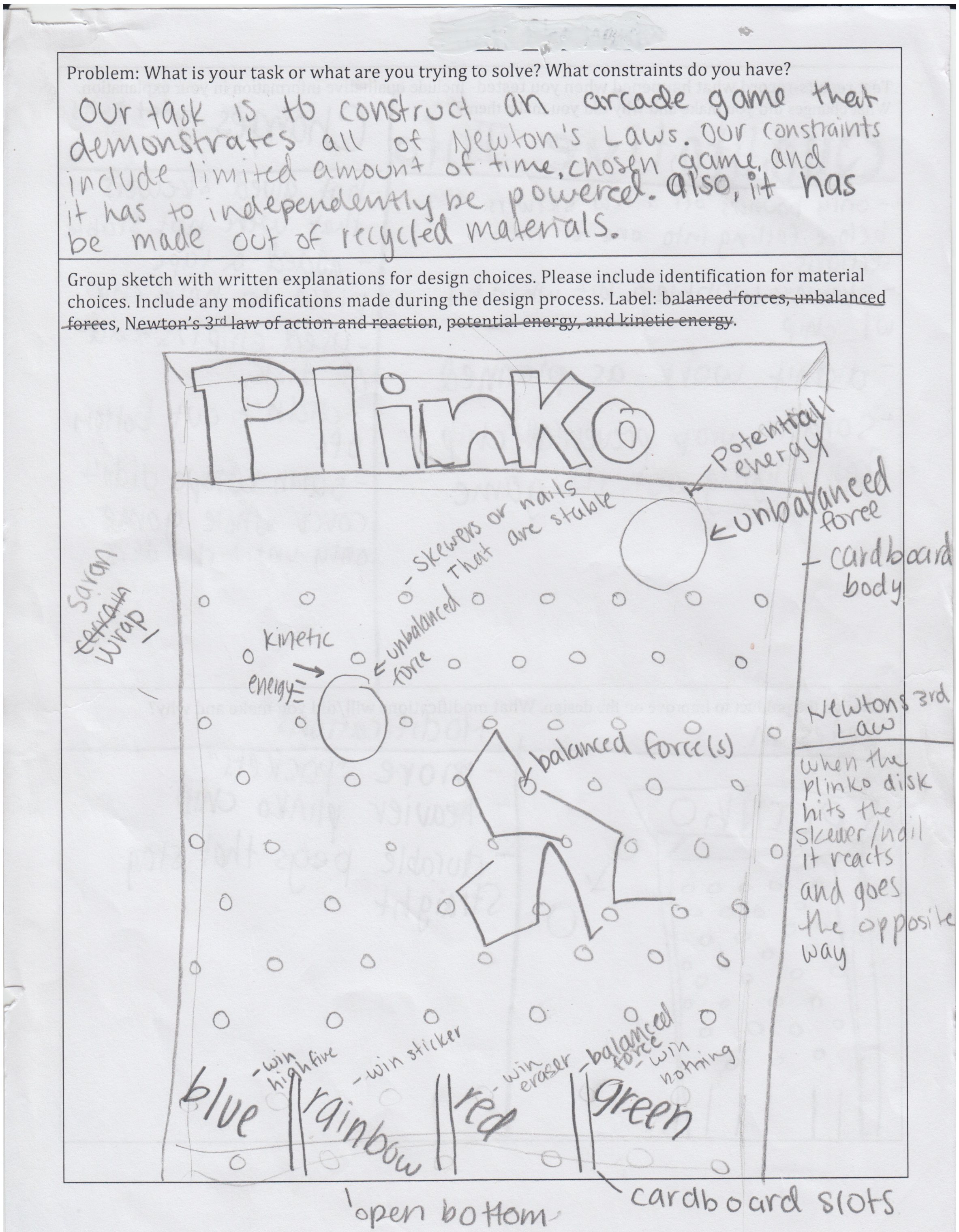
We used Abi's design of a cardboard square, but we tripled the the cardboard to provide weight and strength.

We used kate's design of a straw taped to the balloon and car to make the car move in a straight direction.

Test Results- Record what happened when you tested and why. Include qualitative and quantitative information.

Qualitative	Quantitative
-The back wheels of our car were milk bottle lids. -The front wheels of our car were water bottle lids. -The car was rainbow duck taped to the cardboard. - Our car turned sideways on the first few trials, so we had to straighten the wheels each time.	- Our one balloon popped on the second trial. - On the first trial, our car travelled 10 or less feet

Figure 2. Student work for balloon car activity using engineering design worksheet.



Problem: What is your task or what are you trying to solve? What constraints do you have?

Our task is to construct an arcade game that demonstrates all of Newton's Laws. Our constraints include limited amount of time, chosen game, and it has to independently be powered. also, it has be made out of recycled materials.

Group sketch with written explanations for design choices. Please include identification for material choices. Include any modifications made during the design process. Label: ~~balanced forces, unbalanced forces~~, ~~Newton's 3rd law of action and reaction~~, ~~potential energy, and kinetic energy~~.

Figure 3. Student work for cardboard game exploring action and reaction relationship using engineering design worksheet.

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Appendix A

Engineering design worksheets created for students to demonstrate work.

Task: Build a balloon car out of everyday recycled materials that can travel at least 10 ft using a balloon to power it. What constraints do you have to achieve the task?
Design and draw a picture of a balloon car you think would be effective to travel the greatest distance or the fastest speed. Label and explain your ideas. Include an explanation for every recycled or repurposed material used. (Why did you choose that material)

Group sketch of design with written explanations for design choices. **Your group must use at least one aspect of each person's individual design in group design.** Label each group members idea used as well as parts of balloon car in detail. Include any changes made during building.
Test Results- Record what happened when you tested and why. Include qualitative and quantitative information.
Redesign Group Plan- What modifications will/were made to make the car better and why were they made? Include sketch and written description.
Re-Test Group Results- Record what happened when you tested and why. Include qualitative and quantitative information.

Analysis- Explain how the project went using the following guiding questions if needed: What do you feel went well and why, what do you feel didn't go well and why, why did your group decide on the design that was chosen, how would you modify the car to make it better, how did your results compare to your classmates? You may add any information important to your reflection of the process and results.
Include a final sketch of your design and explain where all 3 of Newton's laws took place during the project. Explain where the relationship between mass, force, and acceleration was observed.

Appendix B

Engineering design grading rubric for student work.

Skill	Advanced 5	Proficient 4.5	Basic 3.5	Below Basic 2.5	None 0
Problem	Student accurately explains the task with clear and concise writing. Clearly describes limitations of task.	Student explains task with clear thought. Address limitations of project	Student acknowledges task and explains task with some thought. Limitations limited or lack of understanding.	Student acknowledges task. No limitations listed.	No evidence provided
Design	Design is neatly and clearly drawn. Clear explanations for design. All aspects for design labeled and explained.	Design is neatly and clearly drawn. Clear explanations for design. Most aspects for design labeled and explained.	Design is neatly drawn. Explanations included in design but not clear. Some aspects labeled or not clearly explained.	Design is drawn. Explanations not clear or design not labeled and explained.	No evidence provided
Evaluation	Modifications clearly identified and explained as to reason modifications made. Writing and explanations are clear.	Modifications identified and some explanations included for modifications. Writing and explanations are logical.	Some modifications identified with limited explanations for modifications. Writing and explanations are present but confusing.	Limited modifications identified with little to no explanations for modifications. Writing and explanations are unclear or not present.	No evidence provided

Group	Group plan includes at least one aspect from each group member's previous design. Designs are neat and clearly drawn. Clear explanations for design and all aspects for design labeled and explained.	Group plan includes at least one aspect from each group member's previous design. Design is neat and clearly drawn. Clear explanations for design. Most aspects for design labeled and explained.	Group plan includes at least one aspect from each group member's previous design. Design is neatly drawn. Explanations included but not clear. Some aspects labeled or not clearly explained.	Group plan included but missing or more aspect from each group member's previous design. Design is drawn. Explanations not clear or design not labeled and explained.	No evidence provided
Redesign	Redesign clearly identifies modifications made to design for improvement. Clear explanations and labels provided to support **student thinking**. Writing is clear.	Redesign identifies modifications made to design for improvement. Clear explanations and labels provided to most ideas to support student thinking. Writing is clear.	Redesign identifies some modifications made to design. Explanations included but not clear or doesn't fully support student thinking. Writing is present but confusing.	Redesign identifies minimal modifications. Little or no explanations used to support student thinking. Writing is unclear or not present.	No evidence provided
Analysis	Analysis includes explanations for **student thinking** and clearly demonstrates ideas. Writing accurately identifies process including all aspects included in analysis. Ideas for redesign clear, drawing is neat and new aspects clearly explained.	Analysis includes explanations for student thinking and demonstrates ideas for student understanding. Writing identifies process and includes most aspects included in analysis. Ideas for redesign clear, drawing is clear and new aspects explained.	Analysis includes explanations for student thinking and demonstrates some ideas for student understanding. Writing identifies most of the process and some aspects included in analysis. Ideas for redesign mostly clear, drawing is present, and new aspects present.	Analysis includes some explanations for student thinking and demonstrates limited ideas for student understanding. Writing identifies limited process and minimal aspects included in analysis. Ideas for redesign unclear, drawing is unclear, and new aspects not evident.	No evidence provided