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Project-Based Learning's Effect on Students' Understanding and Usage of the Engineering Design Process

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An Action Research Report

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Abstract

This action research study examined project-based learning's effect on students' understanding and usage of the Engineering Design Process. The study took place in an elementary school with seventy-two 5th grade participants. Students participated in three project-based learning activities throughout the study. The data was collected over a six week period with the use of pre- and post-assessments, teacher observations, an Engineering Design Process rubric, and student journaling. The results of the study showed that students' understanding and usage of the Engineering Design Process increased throughout the study. In conclusion, a project-based learning environment supports a positive effect on students' understanding and usage of the Engineering Design Process. This project-based learning methodology has the potential to result in positive student gains in other topics and subject areas.

Keywords: Project-Based Learning, Engineering Design Process, Inquiry

In my elementary school building, students are encouraged to explore their interests and experiment with their ideas. Engineering is emphasized in our classrooms as we recognize that our students are natural-born engineers.

Students love to tinker, build, and create. However, this passion for learning is often lost as students move into the school systems. The Engineering Design Process is often taught in a lecture-style setting. This methodology may lead to disinterest and lack depth of knowledge in regards to engineering. To remedy this effect, my colleagues and I determined we should explore other methodologies to more effectively teach these concepts. The hands-on method of project-based learning (PBL) immerses the students in an inquiry-based experience that ignites students' interests. Teaching the Engineering Design Process in a project-based learning environment has the potential to increase student achievement while also drawing on the students' natural enjoyment of hands-on inquiry-based learning.

I am the K-6 Technology & Innovation Teacher in my elementary school building. I conducted this study to research and determine how involvement in a project-based learning environment affects students' understanding and usage of the Engineering Design Process. The study took place over six weeks in a K-6 elementary school. Seventy-two students took part in the study over a six week period.

Literature Review

Introduction

While most students are proficient in solving paper-pencil questions, they often lack proficiency at providing optimal solutions to project-based problems that require systematic learning strategy, innovation, problem-solving, and execution (Chua, Yang, & Leo, 2014). It has been documented that students who take part in a project-based learning environment have shown increases in problem-solving abilities, knowledge scores, and artifact performance when compared to traditional lecture-style classrooms (Chua, Yang, & Leo, 2014). Project-based learning is formatted for students to strengthen self-learning and cooperative learning as they are active in the learning process.

When students are active in the learning process, they are moving from being passive recipients of knowledge to participants as they analyze, synthesize, and evaluate information (Hirca, 2011). Active learning emphasizes the development of students' skills (Hirca, 2011). Exposure to a project-based learning environment leads to a deeper understanding of the usage and framework of the Engineering Design Process.

This paper serves as a review of literature explaining the definition of the project-based learning environment that fosters growth of the usage and understanding of the Engineering Design Process, and the expected student learning outcomes as students are immersed in a project-based learning environment. Project-based learning promotes the use of the inquiry model which encourages a greater understanding of content and skills (Hirca, 2011). The inquiry process engages students in framing their questions and provides structures to help them make sense of information, synthesize ideas, and communicate their findings to a real audience. Designing for inquiry in the project-based learning environment requires a shift in practice as hard work that motivates students to dig deeper into the learning experience (Keeling, 2014).

Project-Based Learning Environment

Project-based learning is a student-centered approach that engages students as they use the inquiry process as they are given a real-world situation or problem to solve (Dalimonte, 2013) while also being aligned to content standards. The goal is that students become aware of the connections between the academic knowledge and its applications in real life while gaining a deeper understanding of concepts (Sahin & Top, 2015).

In a project-based learning environment, the focus in the classroom shifts from teacher-led to student-led. The students become the navigators directing their learning through the inquiry process and the development of project-based learning experiences. The teacher becomes more of a facilitator as the focus in the classroom moves from the instructor teaching the content to students learning the content through the inquiry process and problem solving (Dalimonte, 2013). The instructor provides the students with a list of guidelines, a timeline, and helps them create a plan of action for the project (Coyne, Hollas, & Potter, 2016). The students will decide how they will solve the project-based learning project through the use of the inquiry process. Due to the nature of project-based learning, the students may arrive at a solution which is not an area of expertise for the instructor (Smith & Cook, 2012). These situations create discussion opportunities and the possibility of a new and exciting solution to the problem (Smith & Cook, 2012).

The Inquiry Process

The inquiry process is about using logic and reasoning from data while applying scientific techniques and skills to solve real-world problems (Padilla, 2010). The National Research Council (2000) identified several essential features that describe what the learner does in inquiry. These features are broad components of inquiry which include when the learner engages with a scientific question, participates in the design of procedures, gives priority to gathering evidence, formulates explanations, connects explanations to scientific knowledge, and communicates explanations (National Research Council, 2000).

As students move through the inquiry process, it is presented in a scaffolded design. Smith and Cook (2012) state that scaffolding changes difficult and complex problems to more manageable tasks within the learning constraints of the student. The instructor provides the guiding foundation for structured inquiry in a scaffolded design. Scaffolding strategies designed for the inquiry process include facilitating ongoing articulation of various aspects of the investigation, supporting explanation building and development of working hypotheses, and facilitating monitoring, reflection, and revision (Land & Zembal-Saul, 2003). Often, the inquiry process is used in a collaborative environment as students move through the process with peers (Dalimonte, 2013).

Engineering Design Process

Engineers are challenged to think “outside of the box” as they work to envision, design, create, and build solutions to problems. They utilize a creative problem-solving approach which involves using the Engineering Design Process to formulate their solutions. The Engineering Design Process is made up of several steps that the engineer will go through to process the optimal solution. The Engineering Design Process begins with asking: What is the problem? The engineer then goes on to brainstorm, select an idea to develop, create a plan, develop and test a prototype, improves the prototype, then completes the process by reflecting and presenting the findings (Lottero-Perdue, Roland, Turner, & Pettitt, 2013).

Assessment of Growth

When assessing the outcomes in a project-based environment, the assessments must be able to measure both the driving question and the educational goal (Coyne, Hollas, and Potter, 2016). There are many methods of assessment to determine student growth and gains in regards to academic and 21st-century skills. The project-based learning model provides multiple avenues to calculate this data.

Formative and summative assessments may be used to assess learning outcomes in a project-based learning environment. Instructors may use short summative assessment tasks to guide students toward an improvement in collaboration with other members by emphasizing the sense of individual accountability or toward a development of their content knowledge (Capraro, Capraro, & Morgan, 2013). The formative project-based learning assessment encompasses an accumulation of learning artifacts, which are assembled by students through clear and explicit directions from the instructor (Capraro, Capraro, & Morgan, 2013). The formative assessments are intended to help students apply the knowledge and provide a sense of ownership of the knowledge. Project-based learning assessments may evaluate both individual and group performance (Capraro, Capraro, and Morgan, 2013).

As found in a study conducted by Sahin and Top (2013), student interviews provided evidence of increased conceptual understanding and further development of 21st-century skills, including self-confidence, technology skills, life and career skills, communication skills, and collaborative skills. Interviews allow the students the opportunities to provide feedback about their levels of understanding. As interviews are conducted, the interviews act as a self-reflection period. These interviews also allow students to indicate their development of 21st-century skills that are directly related to the inquiry process. As Grover and Stovall (2015), found with their project-based learning study, students indicated that they developed better ways to find information, problem solve, and work in a team.

Rubrics are another form of assessment that provides measurable steps for students to achieve a learning goal. The rubrics may be created by the instructor, students, or a combination of both. Allowing students to have input in the rubric creation provides them with more ownership in the process. As students or teams are working through or complete the project, they evaluate their process against the rubric they helped to create (Dilamonte, 2013). Rubrics allow students to self-assess and monitor their progress.

Digital portfolios are another means of assessment that allow students to track their learning and organize the artifacts that represent their progress. These artifacts include multimedia presentations, diagrams, photos, and more. Portfolios allow for the instructor to easily track student progress as it is a representation of their learning. Portfolios and technology-based tools can be used to help learners reflect on and organize ideas to make learners' thinking more explicit and visible (Land & Zembal-Saul 2003).

As students complete a project-based learning project, they may demonstrate their learning by sharing it with an audience. This includes sharing a multimedia presentation, lecture, demonstration of prototypes, and more. This allows for the audience to gauge how much the student has learned and grown through the project-based inquiry process. Sharing work with outside audiences has both cognitive and motivational benefits and supports students in the process of seeing themselves as writers, readers, and creators who make contributions beyond school. (Spires, Hervey, Morris, & Stelpflug, 2012)

Positive Student Growth and Gains in Previous Research

If conducted properly, students should display a deeper understanding of the content knowledge after completing a project-based learning assignment. Sahin and Top (2015) noted that academically, students have displayed great knowledge of content from pre- to post-assessment after being immersed in a project-based learning assignment. As students went through the inquiry process with their project-based learning assignment, students were able to reflect on the strengths and weaknesses of their solutions (Capraro, Capraro, & Morgan, 2013) which demonstrate critical thinking skills.

The inquiry process is an inductive learning strategy that enables learners to construct and process knowledge, deep reasoning skills, and to increase interest and learning motivation (Avsec & Kocijancic 2016). Project-based learning also draws on real life situations which is believed to lead to a higher content retention effect. (Yasin & Rahman, 2011).

Students further develop their 21st-century skills as they work through the project-based learning experience. Students learn to work in teams and create norms to ensure that students are respecting other's opinions when providing their ideas and offering feedback (Coyne, Hollas, and Potter, 2016). Collaboration can lead to the generation of new knowledge (Saab, Joolingen, & Hout-Wolters 2012). In a project-based learning experience, students are encouraged to collaborate with group members while also developing their independent learning skills and knowledge (Smith & Cook, 2012).

Students typically rate project-based learning lessons as more interesting or enjoyable because they can find their "niche" within each project (Hirca, 2011). Students' engagement and learning will be more meaningful when they are empowered to conduct the research and suggest a solution to the problem (Yasin & Rahman, 2011). By allowing students to explore, research, and experience, project-based learning encourages a greater understanding of content and skills (Hirca, 2011).

Conclusion

Research continues to surface that has emphasized the importance of teaching our students how to utilize the Engineering Design Process to solve real world problems in a project-based learning environment. Students are gaining a deeper grasp of content knowledge while further developing 21st-century skills when exposed to an environment that fosters inquiry.

This method of teaching breaks away from the teacher-centered classroom and allows the students to choose which route they would like to take to further their learning. This is a model that allows for freedom of choice and accommodates various learning styles and abilities. This type of classroom environment may be utilized and implemented more often as we are preparing our students for a future in which they will need to draw on their critical thinking and problem-solving skills that are developed through the inquiry process along with project-based learning.

Description of the Research Process

Prior to the beginning of the project, the district superintendent granted permission for the project to be conducted and a letter of assent (see Appendix A) was sent home with all 5th grade students. Fifteen of the families selected to opt-out of the research. The data for these students was not utilized in this study. Seventy-two students participated in this six-week action research project. This action research project began during the week of September 8th, 2016.

On the first day of the study, all students completed the Engineering Design Process Pre-Assessment (see Appendix B). This assessment was administered with the purpose of gathering baseline knowledge from the students. This assessment measured the students’ understanding of the Engineering Design Process. The analysis of these results was used to determine the depth of understanding at which the lessons began regarding use of the Engineering Design Process. Students completed the pre-assessment on their iPads as they were able to access it through Schoology, our learning management system. Schoology provided an analysis of the pre-assessment data, which guided the direction and starting point for the second lesson.

After the pre-assessments were administered, the problem-based learning experiences began. Throughout the study, students were posed with various problems. These problems allowed the students to actively take part in the Engineering Design Process to formulate a solution. Students collaborated with their peers as they produced a solution. These problems included designing robots to autonomously complete work, producing solutions to solve community landfill problems, and designing packaging to reduce the harmful impact existing packaging has on the environment as it is disposed of as waste. As with any project-based learning environment, the teacher facilitated the process as students researched and collaborated to solve their project-based learning challenge. This allowed for the freedom for students to explore various routes for solutions. Solutions to these problems were produced in the forms of 3D printed prototypes, cardboard models, multimedia presentations, and more.

As students worked through these problems, an observational tally/notes sheet (see Appendix C) was used to track student learning. These observations recorded when or how a student: (1) engaged in the Engineering Design Process by collaborating with peers as they work through the process, (2) asked critical thinking questions regarding the Engineering Design Process, and (3) demonstrated understanding by discussing the steps of the Engineering Design Process with peers. There was also a place to jot other notes regarding specific statements the students made, observable misunderstanding of concepts, struggles with the Engineering Design Process, etc. Observations occurred during each lesson. There was one fifteen minute observation period during each session. I divided the students into three groups. During each lesson, I observed a different group. For example, during the first lesson, I observed group A. During the second lesson, I observed group B. During the third lesson, I observed group C.

During the fourth lesson, I observed group A. During the fifth lesson, I observed group B. During the sixth lesson, I observed group C.

As students worked through the Engineering Design Process to solve their problems, their work was guided by a rubric (see Appendix D). This rubric explained the steps of the Engineering Design Process students needed to document as they moved through the process. As students produced a solution to their problem, they presented their work to the class. Students regularly compared their learning progress with the learning objectives and outcomes posted on the rubric. In this way, the students informally self-assessed their progress throughout the project. The rubric was used by the teacher to formally assess the students when their projects were completed. The students used this rubric as they worked through each project. During the course of this study, the students completed three project cycles. While the rubric also served as a guide for the students, I only used my formal rubric assessments in my data analysis to help me track student growth of understanding of the Engineering Design Process as each project was completed. Using, filling out and being assessed using a rubric is a normal common practice in a PBL environment.

At the end of each class period, students documented their learning in their student journals. I provided prompts (see Appendix E) to the students to give them direction regarding what I wanted them to write about. These journals allowed me to see their progression as they documented their learning from their perspectives. The journal prompts were specific and varied as they asked students to document their entire progression through the Engineering Design Process. The questions were assigned strategically to align with the content that the student was engaged in. Students have used this type of journaling in my classroom regularly for reflection and assessment, so this was familiar to them. As the students submitted their journal responses, I used the responses to guide our future lessons. I was able to identify weak areas in their learning through their journaling. These journals were stored in Schoology, our learning management system. This allowed me to have immediate access to their journals.

Throughout the study, I continuously analyzed the students' data. By doing so, I was able to purposefully design the upcoming lessons to meet the students' needs regarding the understanding of the Engineering Design Process. The analysis of the data provided a window into the students' learning process and areas in which they were struggling. These trouble areas were addressed in the future lessons.

As the study came to a close, the students completed the post-assessment (see Appendix A). The pre-assessment and the post-assessment included the same questions. The examination and analysis of the pre-assessment results compared to the post-assessment results provided levels of growth and understanding of the Engineering Design Process for each student.

Students presented their projects to the class and explained their learning as they went through the Engineering Design Process. Students projects were also put on display at our 5th grade S.T.E.A.M. (science, technology, engineering, art, and math) Expo. Students had the opportunity to share their learning with parents and members of the community as they presented the solutions to the problems they were given. These presentation opportunities to authentic audiences provided a platform for the students to show what they had learned about the Engineering Design Process.

At the end of the study, all student data that had been gathered throughout the study was analyzed to determine the levels of student growth regarding understanding and usage of the Engineering Design Process.

Timeline of Project-Based Learning Units

New project-based learning units were started on weeks 1, 3, and 5. These project-based learning units required two weeks to complete. All of these units required students to work in teams of two to complete the unit.

The first unit required students to create a robot that could autonomously draw circles. This was a very simple unit that provided clear steps of how to utilize the Engineering Design Process. Students learned the basics about the steps of the Engineering Design Process.

On week three, students were given an environmental problem to solve. These problems revolved around the topics of reducing, reusing, and recycling. Students utilized the Engineering Design Process to develop solutions.

During week five, students were challenged to solve an alternative energy problem. This project required students to use what they had learned in the previous weeks to move through the Engineering Design Process to develop a solution.

The project-based learning units became increasingly more difficult as students further developed their knowledge and understanding of the Engineering Design Process.

Data Analysis

At the conclusion of my research, I analyzed the data to identify themes, trends, and results. Data Collection Tools 1, 2, and 3 provided quantitative data. Data Collection Tool 4 provided qualitative data.

Data Collection Tool #1: Pre and Post-Assessment

The pre-assessment was administered prior to any instruction regarding the Engineering Design Process. The scores of the pre-assessment were low. As noted in Figure 1, the mean score for the pre-assessment was 3.3 out of a possible 10 points. This mean indicated that the students had very minimal prior knowledge regarding the Engineering Design Process. Students were not shown their scores. The students completed the same assessment as a post-assessment. Because of this, the answers to the questions were not revealed to the students. These low scores indicated that my project-based learning units would need to be focused on the basics of the Engineering Design Process.

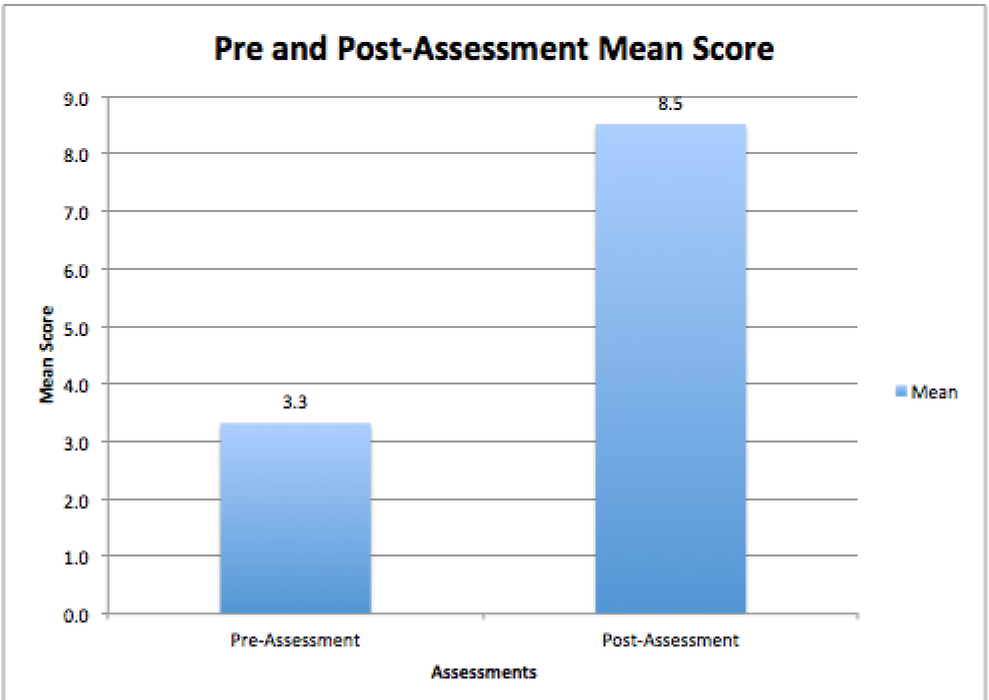

Figure 1. Pre and Post-Assessment Mean Score. Mean scores collected from Pre and Post-Assessment Data Collection Tool #1.

After six weeks of project-based learning instruction, the students were given the post-assessment to assess their knowledge. The pre and post-assessment questions were identical. As noted in Figure 1, students scored a mean score of 8.5 out of a possible 10 points. On average, students' scores raised 5.2 points. Students moved from correctly answering 33% of the questions at the beginning of the action research project to correctly answering 85% of the question at the end of the action research project.

The median score increased from 3.0 on the pre-assessment to 9.0 on the post-assessment. The mode also increased from 3.0 on the pre-assessment to 10.0 on the post assessment. The pre and post-assessment results from the fifteen students who opted out of the action research process were excluded from this data analysis.

Data Collection Tool #2: Observational Tally/Notes Sheet

As the students worked on their project-based learning units, I regularly used an Observational Tally/Notes Sheet to record when students (1) engaged in the engineering design process by collaborating with peers as they work through the process, (2) asked critical thinking questions regarding the engineering design process, and (3) demonstrated understanding by discussing the steps of the engineering design process with peers.

As I analyzed the data, I compared the results from week-to-week as noted in Figure 2. The engagement of the students in the Engineering Design Process by collaborating with peers as they worked through the process increased each week. Students also increased the amount of critical thinking questions they asked regarding the Engineering Design Process as each week passed. The number of students who demonstrated their understanding by discussing the steps of the Engineering Design Process with peers also increased week-to-week with the exception of a drop in week 3.

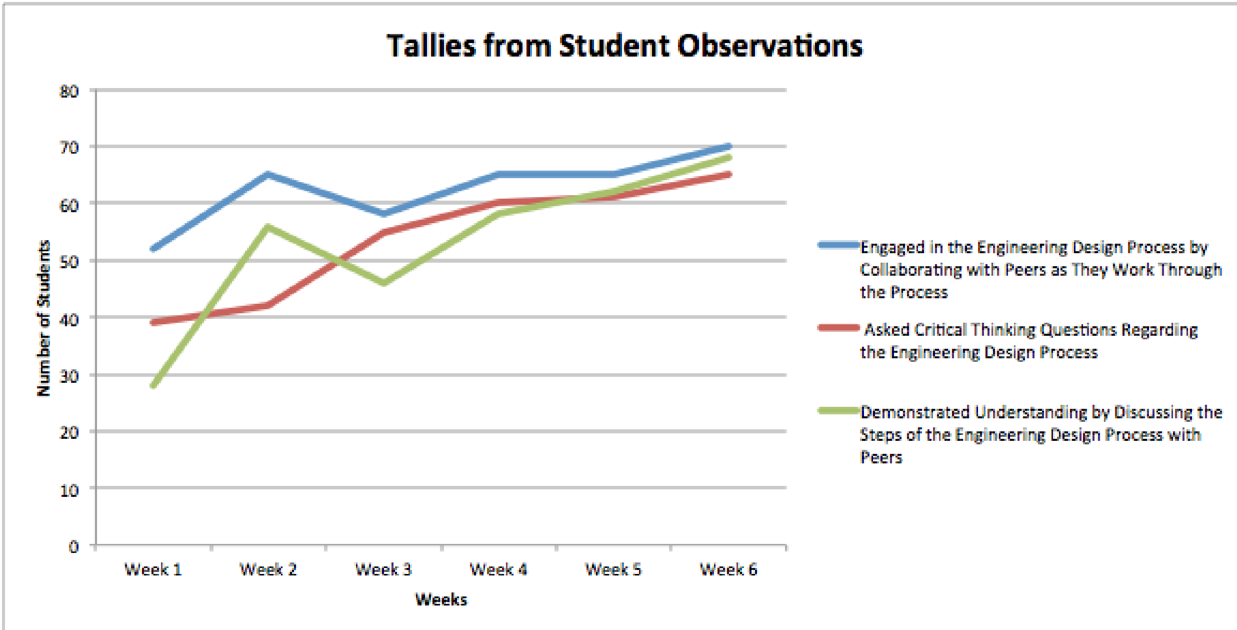

Figure 2. Tallies from Student Observations. Data from the Observational Tallies/Notes Data Collection Tool #2.

The steady increase in these areas are likely due to increased exposure and practice with the Engineering Design Process. Every two weeks, students began a new project-based learning unit. During weeks 1, 3, and 5, students began new project-based learning units. This could be a contributing factor as to why the second week in each project-based learning unit scored higher tally marks than the first week of each unit.

As students completed each project-based learning unit, they appeared increasingly more comfortable with the Engineering Design Process. As students appeared more comfortable and fluent with the Engineering Design Process, the observational tallies increased.

Data Tool #3: Engineering Design Process Rubric

As students began a project-based learning unit, they were given a rubric to guide their learning. Students self-assessed their own knowledge. The higher the score, the closer the student was to meeting all of the expectations on the rubric. The rubric details the expectations that the student needs to display to show their levels of understanding regarding the Engineering Design

Process. This rubric was also used by the teacher to assess how well students displayed their levels of understanding. The rubric was created to be standards-based. An “E” indicates that a student exceeded the state standards. An “M” indicates that a student met the state standards. A “P” indicates that a student partially met the state standards. A “D” indicates that a student did not meet the state standards.

As students self-assessed, they reported their scores. These scores were collected and recorded as noted in Figure 3.

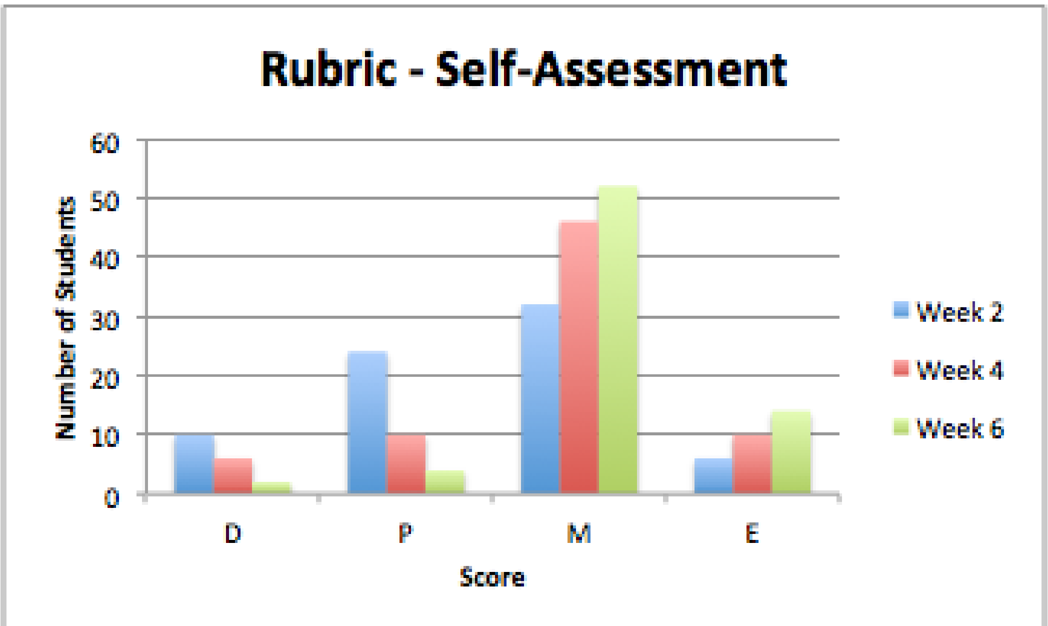

Figure 3. Rubric - Self-Assessment. Students self-assessed with the Engineering Design Process Rubric Data Collection Tool #3.

Students’ self-assessment scores gradually increased as they completed each project at the end of weeks 2, 4, and 6. At the end of week 2, students’ self-assessment scores were the lowest in comparison to weeks 4 and 6. Students scored themselves the highest in week 6.

Figure 4 shows the scores that the students received by the teacher. Students’ self-assessment scores were very close to the scores that were given by the teacher. Due to the detailed expectations in the rubric, students accurately self-assessed their learning and knowledge. Students also became very comfortable with using the rubric for self-assessment as the weeks went on. They developed a firm understanding of the rubric expectations. This may have contributed to their increasing scores from week-to-week.

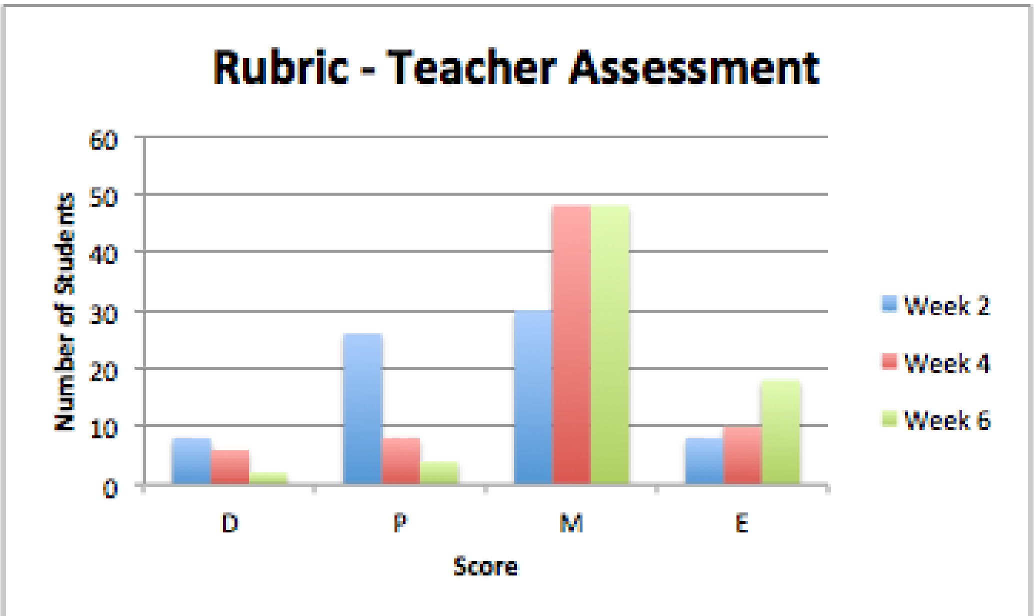

Figure 4. Rubric - Teacher Assessment. The teacher assigned a score reflecting the students' learning in regards to the Engineering Design Process Rubric Data Collection Tool #3.

Data Tool #4: Student Journals

At the end of each week, students completed one to two journal questions. These questions were used as a formative assessment to allow the teacher to see the students' levels of understanding about each question topic.

As the students' journaling was examined, several themes appeared. In week one, students were asked to, "Describe what you know about the Engineering Design Process." Approximately 30% of the students indicated that they knew anything about the Engineering Design Process. The remaining 70% of students wrote, "I don't know" as their response to the question. This was an indicator that most students did not have any prior knowledge about the

Engineering Design Process. As a result, I followed the journaling with a lesson about the basics of the Engineering Design Process.

During week two, students replied to the question, “How do engineers use the Engineering Design Process? How does the Engineering Design Process help engineers? 65% of students indicated that the Engineering Design Process helps engineers build things. 15% of students wrote that the Engineering Design Process helps engineers think. The remaining 20% of students indicated that they did not know how engineers utilize the Engineering Design Process. The majority of students did not make any reference to utilizing prior knowledge as a starting point for inventing and creating solutions to problems. After the journaling was complete, we discussed the importance of engineers using prior knowledge.

The journaling in week three asked, “Why is it important to identify possible solutions at the beginning of the Engineering Design Process? Which solutions did your group identify?” and “As your group choose your solution, what elements made you select this solution? In what ways will your solution solve your problem?” Eighty percent of students wrote about utilizing prior knowledge to form solutions. This was an indicator that students’ were developing their understanding of the “explore” phase of the Engineering Design Process. When answering the journal question about the chosen solutions, 45% of students indicated that they had seen similar solutions before. Ten percent of students were unable to explain their reasonings behind why they chose their solution. The remaining 45% of students indicated that they had done research to generate ideas.

During week four, students were asked, “As you sketched and planned your prototype, how did you decide on the design that you chose?” Forty-five percent of the students replied that they compromised with their partner to agree on the prototype design based on the research they had done. Forty-five percent of students indicated that they had seen solutions of this type before. The remaining 10% did not have previous experiences or research to support their prototype.

Week five asked the students to reply to, “As you tested your solution, in what ways did it solve your problem? In what ways did it not solve your problem? What can be improved?” This was an interesting question to ask as about 25% of the students realized that their solution deviated from their original problem and didn’t solve it. About 50% of the students’ prototypes failed to solve their problem. They were forced to go back to the design stage. The remaining 25% of students succeeded with their first prototype.

Students finished journaling in week six. They responded to the following questions, “As you move back to the step of identifying a solution and reworking your prototype, what changes are you planning to make to improve your outcome? Final question to end the project: How has the Engineering Design Process helped you to find a solution to the problem? What are the benefits of utilizing the engineering design process to solve problems?” The journaling questions this week were pinpointed on the improving stage of the Engineering Design Process. Ninety percent of students responded within the theme of identifying the benefits of moving through the stages of the Engineering Design Process to produce a solution. These students provided lengthy responses detailing how to utilize the Engineering Design Process to successfully develop a solution to a problem. Six percent of students indicated that it helped them think, but did not elaborate on the stages of the Engineering Design Process. Four percent were unable to elaborate about the benefits of utilizing the Engineering Design Process.

Throughout the six weeks of journaling, students gradually provided more and more detail to their journal responses. During weeks five and six, students were able to elaborate to greater depth in their responses to the questions in comparison to weeks one through four.

Action Plan

The results of the data analysis support the idea that students' understanding of the Engineering Design Process was deepened throughout the study. Students ended the study with a greater understanding of the Engineering Design Process. The comparison of the mean score results from the pre and post-assessment show a large difference in the level of understanding of the Engineering Design Process. The pre-assessment mean score was 3.3 and the post-assessment mean score was 8.5 This difference in score demonstrates an increased level of understanding.

As the study went on, students increasingly became more engaged in the Engineering Design Process as noted in the Observational Tallies. Students participated in the activities at a greater rate as the weeks went on. This includes being not only physically engaged, but more mentally engaged as the rigor of their comprehension questions increased. Students became very comfortable accurately discussing and the Engineering Design Process with their peers.

The students also demonstrated increased understanding of the Engineering Design Process as they worked through aligning their learning outcomes with the expectations of the Engineering Design Process rubric. As the research went on, most students demonstrated a firm understanding of the Engineering Design Process as it was described on the rubric. The display and presentation of student learning at the end of each project demonstrated what the students had learned. As each project was completed, the presentations became more and more aligned with the rubric. This was a demonstration of gaining deeper understanding as the study progressed.

Lastly, the students' journal responses were more thorough and accurate as the weeks went on as students responded to the journaling questions. Students sought out less help and guidance as they responded to each journal prompt as the weeks progressed. They became quicker to jump into the responses and write about what they learned. Students seemed to become very comfortable with sharing what they had learned. By the end of the study, barely any students had questions about the Engineering Design Process as they wrote about it in their journals.

All of the data displays that students' understanding and usage of the Engineering Design Process was deepened through their exposure to a project-based learning environment. These results are evidence that this form of practice may be a successful method to utilize as teachers strive for deeper understanding of certain topics. My practice will change to incorporate more project-based learning experiences. Students seemed to genuinely enjoy this type of learning. Many students also commented that they preferred this type of learning over the traditional worksheet and lecture style.

This research demonstrates the benefits of using a project-based learning environment in the classroom. Student learning increased throughout this study. Therefore, it is supported that increased student learning may take place in project-based learning environments when compared to traditional classrooms. It is my hope that additional teachers in the building notice the positive impact that this practice has had and begin to implement project-based learning in their classrooms. An overall shift of teaching methods in our elementary building to more of a hands-on project-based learning style has the potential to drastically increase student learning.

Based on the positive results of this study, I would like to expand the use of project-based learning to other concepts and subject areas. This would require a shift in my teaching style. This type of learning seems to heavily engage the students with positive outcomes. I would like to incorporate this type of learning style in subject areas that tend to be less hands-on, like social studies. This would require a revamp of the curriculum and the way it is traditionally taught, but it may lead to deeper understanding by the students. I would also like to involve students more to increase the inquiry and student choice in these projects. This would move my teaching style to becoming more of a facilitator. As students become more comfortable with project-based learning, I plan to give students more voice in choosing the research topics and areas of exploration.

I am interested in conducting future action research studies to determine the effectiveness of integrating project-based learning environments in other subject areas. This will be the next step in my future research. Conducting additional research will help to identify the most effective learning environments for each subject. It is possible that project-based learning environments in different subject areas may result in different outcomes than the learning outcomes that resulted in this study.

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Appendix A

Project-Based Learning's Effect on Students' Understanding
and Usage of the Engineering Design Process

Assent Form

September 8, 2016

Dear Parents and Guardians,

In addition to being your child's Technology and Innovation teacher, I am a St. Catherine University (St. Kate's) student pursuing a Masters of Education. As a capstone to my program, I need to complete an Action Research project. I am going to study how involvement in a project-based learning environment affects students' understanding and usage of the Engineering Design Process.

In the coming weeks, I will be immersing the students in a project-based learning environment as a regular part of my Technology and Innovation curriculum. All students will participate as members of the class. In order to understand the outcomes, I plan to analyze the results of the exposure to the project-based learning environment to determine the student's growth regarding the understanding and usage of the Engineering Design Process.

The purpose of this letter is to notify you of this research and to allow you the opportunity to exclude your child's data from my study.
If you decide you want your child's data to be in my study, you don't need to do anything at this point.

If you decide you do NOT want your child's data included in my study, please note that on this form below and return it by September 30th, 2016. Note that your child will still participate in the project-based learning environment but his/her data will not be included in my analysis.

In order to help you make an informed decision, please note the following:

- I am working with a faculty member at St. Kate's and an advisor to complete this particular project.
- This project will determine the benefits of using a project-based learning environment to deepen the students' understanding and usage of the Engineering Design Process.

- I will be writing about the results that I get from this research. However, none of the writing that I do will include the name of this school, the names of any students, or any references that would make it possible to identify outcomes connected to a particular student. Other people will not know if your child is in my study.
- The final report of my study will be electronically available online at the St. Kate's library. The goal of sharing my research study is to help other teachers who are also trying to improve their teaching.
- There is no penalty for not having your child's data involved in the study, I will simply delete his or her responses from my data set.

If you have any questions, please feel free to contact me (alarsen@ci.k12.mn.us or 218-545-8800 ext. 6963). You may ask questions now, or if you have any questions later, you can ask me, or my advisor, Allie Brandon at alliebrandon@hotmail.com, who will be happy to answer them. If you have questions or concerns regarding the study, and would like to talk to someone other than the researcher, you may also contact Dr. John Schmitt, Chair of the St. Catherine University Institutional Review Board, at (651) 690-7739.

You may keep a copy of this form for your records.

Allison Larsen 9/13/16
Technology & Innovation Teacher

OPT OUT: Parents, in order to exclude your child's data from the study, please sign and return by September 30, 2016.
I do NOT want my child's data to be included in this study.

______________________________ ________________
Signature of Parent Date

Appendix B

Engineering Design Process - Pre-Assessment

Questions 1–5 of 5 | Page 1 of 1

Question 1 (1 point)

What is the Engineering Design Process? When or why would you use the Engineering Design Process?

Question 2 (6 points)

Below are the steps to the Engineering Design Process. Place them in the correct order. Place the first step at the top of the list and the last step at the bottom of the list.

1. Try It Out
2. What's The Problem?
3. Explore
4. Make It Better
5. Design
6. Create

Question 3 (6 points)

Match each step of the Engineering Design Process with the correct description of what happens at that step.

Column A

1. ____ What's The Problem?
2. ____ Explore
3. ____ Design
4. ____ Create
5. ____ Try It Out
6. ____ Make It Better

Column B

a. Use your plan to build your idea.

b. What's the challenge? What are the limits? How can you solve it?

c. Find out what others have done. Gather materials and play with them.

d. Think about how your design could be improved. Modify your design and try again.

e. Test your idea.

f. Think up lost of ideas. Pick one and make a plan. Make a drawing or a model.

Question 4 (1 point)

Is it beneficial for engineers to "make it better" and go through the Engineering Design Process several times when finding a solution? Provide a statement to support your answer.

Question 5 (1 point)

As engineers move through the Engineering Design Process, is it important for engineers to study history? Provide a statement to support your answer.

Appendix C

Observational Tally/Notes Sheet

Student #1: ____
Date:_________________________________ Time: _______________________________

Engages in the engineering design process by collaborating with peers as they work through the process	Asks critical thinking questions regarding the engineering design process	Demonstrates understanding by discussing the steps of the engineering design process with peers	Other Notes

Student #2: ____
Date:_________________________________ Time: _______________________________

Engages in the engineering design process by collaborating with peers as they work through the process	Asks critical thinking questions regarding the engineering design process	Demonstrates understanding by discussing the steps of the engineering design process with peers	Other Notes

Observational Tally/Notes Sheet

Student #3: ____
Date:_______________________________ Time: _____________________________

Engages in the engineering design process by collaborating with peers as they work through the process	Asks critical thinking questions regarding the engineering design process	Demonstrates understanding by discussing the steps of the engineering design process with peers	Other Notes

Student #4: ____
Date:_______________________________ Time: _____________________________

Engages in the engineering design process by collaborating with peers as they work through the process	Asks critical thinking questions regarding the engineering design process	Demonstrates understanding by discussing the steps of the engineering design process with peers	Other Notes

Appendix D

Engineering Design Process

You will be creating a presentation with the platform of your choice to display and explain your learning as you worked through the engineering design process as you built your solution.

You must include (in this order):

1. **What's the problem?** What you are trying to accomplish? What problem are you trying to solve? What are possible limitations of producing your solution? (Ex. only certain materials, time frame, etc.)?
2. **Explore** – What prior knowledge did you have before starting this project?
3. **Design** – Explain what design your group started with and why. Where did you find information to guide your building process?
4. **Create** – Show photos of your completed solution. As you change and alter the design, be sure to include photos of this as well.
5. **Try it out** – What happened during your first attempt, second attempt, and so on? Describe what happened.
6. **Make it better** – What did you change after your trials?
7. **Results** – What was the most successful solution that you achieved? What design worked best?
8. **What I learned** – What did you learn about the engineering design process?

** You must include photos of your prototype/design.

Grading Rubric:

E - You included all of the requirements listed above. Your information is clear and easy to understand. Your information is written in complete sentences with proper grammar. You researched possible solutions to this problem and explained how each operates. You also researched how other engineers have solved similar problems and included this information in your presentation. You displayed all of this information in your presentation.

M – You included all of the requirements listed above. Your information is clear and easy to understand. Your information is written in complete sentences with proper grammar.

P - You included most of the requirements listed above, but some are missing. Your information is slightly unclear and confusing. Your information is not written in complete sentences with proper grammar.

D - You included less than half of the requirements listed above. Your information is very unclear and confusing. Your information is not written in complete sentences with proper grammar.

Appendix E

Student Journal Questions

The students will be given prompts to answer in their student journals after each lesson. The progress of the lesson will determine whether the students will respond to one or two questions. Questions will be asked in the following order.

1. Describe what you know about the engineering design process.
2. How do engineers use the engineering design process? How does the engineering design process help engineers?
3. Why is it important to identify possible solutions at the beginning of the engineering design process? Which solutions did your group identify?
4. As your group choose your solution, what elements made you select this solution? In what ways will your solution solve your problem?
5. As you sketched and planned your prototype, how did you decide on the design that you chose?
6. As you tested your solution, in in what ways did it solve your problem? In what ways did it not solve your problem? What can be improved?
7. As you move back to the step of identifying a solution and reworking your prototype, what changes are you planning to make to improve your outcome?
8. Final question to end the project: How has the engineering design process helped you to find a solution to the problem? What are the benefits of utilizing the engineering design process to solve problems?