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Scaffolding the Implementation of the Engineering Design Process within STEM Based Projects.

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in fulfillment of final requirements for the MAED degree

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Abstract

The purpose of this research was to improve student understanding and use of the engineering design process by scaffolding instruction of implementation during STEM project-based learning. The study was conducted in a fifth-grade engineering class and a seventh and eighth grade technology class with a total of 79 participants. The researchers collected data through pre and post student questionnaires, student checklists, researcher observations and reflection journals. Findings indicated that scaffolding instruction improved student understanding and implementation of the engineering design process. Further research could indicate the effectiveness of teaching best practices within each step of the process and further understanding within STEM project-based learning activities.

Keywords: Engineering design-process, scaffolding, project-based learning

As the global society continues to expand, we are finding that the ways in which students solve problems must grow as well. Students often use problem-solving skills that envelop knowledge from a variety of courses, coming to an educated solution synthesized from their academia. Some of the most used curricula to solve problems involves a culmination of Science, Technology, Engineering and Mathematics (STEM).

A common method of combining these areas to solve problems is referred to as the Engineering Design Process, also described as a systematic method of solving problems. This method has been shown to increase the likelihood of a successful solution to a problem for adults and students (Kelley, 2009). The iterative process involves identifying a problem, brainstorming ideas, research, planning, designing, constructing, testing, and making necessary revisions (Draper, 2008). When the process is complete, the results are communicated, demonstrating the solution to be effective or not.

Within the process, there are countless struggles that can arise, each within the individual steps of the design. How teams utilize the process is differs with problem being solved. As students learn how to solve problems many use different methods developed from their personal experiences. The engineering design process has been deemed a successful method for solving problems but is not always an intuitive process for all students as they learn how to use the separate steps.

Hands-on learning activities are a common teaching strategy to implement such design-based problems. Engineering curriculum can apply real-world facets of the career, making technology and engineering classes an environment where hands-on discovery thrives. Students can develop needed professional skills through their use of the engineering design process. Experiences of research, testing and working collaboratively help promote hands-on learning and

problem-solving experiences for students in all schools (Bell, 2010). The methods have been proven to benefit student inquiry, understanding and career skills.

This study was conducted in an elementary engineering class with fifth graders as well as in a middle school technology education class with seventh and eighth graders. Problem-solving skills are taught in these classes while incorporating math, science, and technology when possible. The researchers observed that students were having difficulties following the engineering design process steps sequentially and sometimes skipped steps within the process completely. The researchers noticed that this led to students having different results in their final solutions or being disappointed with their final results.

This study attempted to collect information on student use of the process based on scaffolding the various steps within it. Instead of teaching the steps of the process and letting students work through its entirety at the pace they see fit, the methods were taught gradually with key instruction of the nuances of each step (Mangold and Robinson, 2013). Through scaffolding the implementation, each step could be analyzed on its use and understanding within each team. The goal when teaching the engineering design process is modified based on the age group being taught and the concepts at hand.

The lessons taught during the research period focused on teaching individual steps within the engineering design process. Students were given examples of what was expected of them at each step and questions to guide their learning. The purpose of our action research project is to improve student understanding and use of the engineering design process by scaffolding instruction during STEM project-based learning.

Review of Literature

The 21st Century learning environment is a rapidly evolving setting, one in which student learning encompasses a variety of subjects, STEM (Science, Technology, Engineering, Mathematics) education being a prime example. Dearing and Daugherty (2004) found that concepts most needed in Technology Education courses consisted of technological literacy, brainstorming, communicating ideas, teamwork, interpersonal skills, dealing with change, and the effects of technology and engineering on the world. Several of these skills are utilized within the use of the engineering design process. The cross-curricular benefits of implementing engineering in the elementary and middle school setting help support the increased need for engineers in the United States. Wicklein (2006) mentions that the U.S has an inadequate number of engineers entering the workforce due to a near 50% engineering student attrition rate in colleges. This would also supply students with real-world problem-solving experiences. To understand the learning experience an engineering design-based lesson can provide, educators should know what effects that scaffolding instruction will have on student implementation of the engineering design process in the elementary and middle school STEM classroom. Engineering based lessons provide students with real-world career-based scenarios that require them to inquire, develop solutions to problems that contain overarching conceptual objectives (Mangold & Robinson 2013). As these engineering-based scenarios often incorporate difficult concepts from other disciplines, scaffolding the approach of the design process can yield greater results for students (Mangold and Robinson, 2013). This literature review suggests scaffolding in the teaching of the engineering design process to improve students' ability to solve problems.

The Engineering Design Process

The engineering design process is a decision-making method used by engineers to develop a solution that solves a problem and meets a human need or want (Draper, 2008; Mangold, & Robinson 2013). There are numerous interpretations of the engineering design process that use a combination of elements and steps that engineers and educators can use (Draper 2008; Lachapelle, & Cunningham 2010). Steps in the process include identifying a problem or need, brainstorming ideas, researching the problem or existing solutions, developing a plan or design to meet the need or solve the problem, building a model or prototype, testing the model or prototype, making improvements to the design based on testing, and communication of the final solution (Draper, 2008). The engineering design process is iterative, open-ended with many possible solutions to the need or problem, and a stimulus to systems thinking, modeling, and analysis (Mangold, & Robinson 2013). The engineering design process is a valuable tool students can use to solve problems throughout content areas in school and for everyday problems. The engineering design process is a tool that teachers can incorporate into their curriculum to improve students' problem-solving skills and introduce students to engineering concepts (Mangold, & Robinson 2013). Kelley (2009) suggests that engineering-based curriculum aides students to think through all aspects of an engineering design process, similar to real engineering case studies. These experiences help to provide both teachers and students opportunities to use a variety of learning strategies. According to Swinson, Clark, Ernst, and Sutton, (2016), "These experiences provide performance-based tasks that not only promote conceptual understanding, but also simultaneously build contemporary industry knowledge and ability" (p.11). Engineering design-based projects can help students connect and create narrative description/discussions, analytical calculations, graphical explanations and use physical creation (Wicklein, 2006).

Students also have increased motivation for solving problems when continually exposed and apply the engineering design process (DiFrancesca, Lee, & McIntyre 2014). Grant and Branch (2005), suggest that learners who have a personal interest and the opportunity to pursue it are more likely to invest in their path to learning. It is a priority for engineering educators that students possess high levels of motivation when participating in coursework, enhancing the experience (Husman, 2010). Grant & Branch noted, “pedagogy that fosters personal interests and interactions with peers, experts, resources, and technologies seems to offer promising alternatives to teacher-centered instruction” (p.66).

Students using engineering design in their classes are more likely to make connections and conclusions to real-world applications (Kelley, 2009). The presented scenarios ask students to operate as professionals and exercise collaboration. Teachers should design problems to be student driven, maintain direction in the content learned, be relevant to students lives and experiences, provide ample rigor through the student learning process and provoke enduring understanding (Krauss, 2013). These project-based learning scenarios often require students to utilize knowledge or skill sets from other content areas, providing potential insight into broad and realistic career-based experiences.

Incorporating other content areas

One development in education has been the implementation of STEM. Using engineering-based problems would provide greater learning opportunities for integrating these subjects into the curriculum and allow for scaffolding with higher detail (Wicklein, 2006). According to Mangold and Robinson (2013), “the engineering design process provides an ideal platform for integrating mathematics, science, and technology” (p.6). Rehmat and Owens (2016) also found that incorporating literacy and math with engineering concepts will make learning

more comprehensive, expose students to real-world problem-solving skills and support learning through the engineering design process.

Professionals seldom work alone and often require a team of colleagues to be experts in different areas, much like group work among students. Krauss and Boss (2013), found, “When students are confronted with real-world problems, they may need more than one set of disciplinary lenses to ‘see’ a complex issue or design a solution” (p. 68). A well designed and focused engineering curriculum will benefit a school’s overall curriculum (Draper, 2008). Thinking across disciplines can be a key component of a project-based learning experiences when working on a solution, and especially when performed in teams (Krauss & Boss, 2013). Students have reported that after participating, they began to make increased connections in the real world as to how their skills apply to management and collaboration skills (Sahin & Top, 2015). The skills needed in modern occupations require professionals and experts to perform duties collaboratively within a team to complete a shared task. Quality understanding among disciplines should be purposeful, grounded in disciplines, integrative and thoughtful (Krauss & Boss, 2013). As students work on a project, their path to a solution may vary depending on the skills and knowledge learned across other disciplines and experiences (Krauss & Boss, 2013).

Guided Inquiry

A pedagogical approach that is becoming more accepted in engineering education is guided inquiry. Guided inquiry was first developed for chemistry curricula but has been adopted across other disciplines such as engineering education due to evidence showing the effectiveness of the strategy (Chase, Pakhira, & Stains, 2013). Toma and Greca (2018) defined guided inquiry as “as a set of activities that seek to assimilate the learning of science and the processes and strategies that scientists follow to resolve problems in real world situations” (p.1385). Using this

strategy gives students the opportunity to learn on their own while interacting with objects that stimulate their curiosity as they develop ideas and problem-solving skills (Toma and Greca, 2018). Guided inquiry is also an approach that allows students to learn in groups. Douglas and Chiu (2012) suggest that in the ideal guided learning lesson, students work in groups on activities based on learning cycles allowing students to understand concepts collaboratively. Toma and Greca's (2018) methodology used a four phased approach to inquiry. The first phase introduced students with the engineering-based problem through an invitation to inquiry (Toma and Greca, 2018). The second phase engaged students in guided inquiry by having them conduct experiments and discuss their results. In the third phase students used open inquiry to look at results from tests conducted to find ways to improve their designs. Finally, in the last phase students engaged in inquiry resolution by proposing and implementing technology that solved the initial engineering problem.

Research has shown that implementing guided inquiry into STEM curriculum may increase students understanding, overall grades, and attitudes towards these subjects. Douglas and Chiu (2012) found that implementing guided inquiry into an engineering materials college course significantly increase students' overall grades. While Toma and Greca (2018) found that using a inquiry methodology with elementary students increased students attitudes and fostered learning.

Scaffolding

Scaffolding is a strategy that has been researched and promoted as a way to teach the knowledge and process skills within problem-solving, inquiry, and the design process (Chen, Rovegno, Cone, & Cone, 2012). Scaffolding is defined as a process "that enables children or a novice to solve a problem, carry out a task, or achieve a goal which would be beyond their

unassisted effort“ (Chen, Rovegno, Cone, & Cone, 2012, p. 222). Welty and Stricker (2012) suggest that teaching the engineering design process should start simple and become more sophisticated as students gain knowledge. While planning these learning experiences, an educator must consider the curriculum and the learning objectives desired (Krauss, 2013). The scaffolding of a project-oriented task may also be planned to incorporate related disciplines and curricula.

Mangold and Robinson (2013) approached teaching the engineering design process by first introducing the steps of the engineering design process through short activities worked on as a class. In the second phase each student picked one of four predetermined problems to work through as homework using the design process. For the final phase, students worked in groups to complete a design project using the engineering design process. Mangold and Robinson (2013) reported that students had an increased understanding of the engineering design process based on pre and post test results. It was also noted that students appreciated the engineering design process being broken down into more manageable parts (Mangold & Robinson, 2013). This approach allowed the students to chip away at the problem and not feel so overwhelmed by the overall scope of the project (2013).

Engineering based real-world problems can incorporate concepts from several disciplines. Krauss and Boss (2013) state that, “NGSS (Next Generation Science Standards) are organized around core ideas and crosscutting concepts” (p.107). It is recommended by the NGSS that students spend more time operating as scientists. These actions are promoted through open inquiry-based scenarios, which can lead to improved problem solving abilities and increased retention, leading students to behave more like experts than novices in an area (Krauss & Boss, 2013). These areas can also be planned to purvey life connections, providing a bridge

for students to understand how the solutions are applied in careers. This will allow students to achieve the most potential learning from a project-based scenario, but cannot be done without intentional planning from the teacher (Krauss & Boss, 2013).

Discussion

With the need for students to compete, communicate and interact successfully on a global scale, they will need a strong basis of critical thinking and problem-solving skills (Mangold & Robinson, 2013). Engineering based education problems integrate applications of scientific, mathematical, and technological concepts that can increase student ability in communicating and participating in higher-level thinking (Mangold & Robinson, 2013). Adding student centered learning with digital elements can help students who may typically struggle, based on the leaps of imagination and creativity in project-based settings (Moon & Joo, 2015). The steps of the design process can be implemented in smaller pieces to increase student understanding of developing problem solutions, cross-curricular content and real life applications. Scaffolding the instruction and using guided inquiry to teach each step in the process will help students to develop a deeper understanding, higher quality communication, improved strategies, and proper implementation of solutions. This implementation of a project-based experience should amount to greater potential learning by students of all levels.

Methodology

This project was designed to better understand the effectiveness of scaffolding instruction of the engineering design-process in a 5th grade engineering class and a middle school gateway technology class. All students participating in the research received parental permission form (Appendix A). All of our students' parents allowed them to participate in the research. Multiple data sources were used to better understand how scaffolding with guided inquiry affected students' ability to implement and understand the engineering design-process. Items used to collect data included pre- and post-questionnaires, a checklist to assess students' documented work, observations of engineering teams' work through lesson activities, and journals entries made by the researchers after each lesson.

The 90 students participating in the research were given pre-questionnaires (Appendix B) to assess their knowledge and understanding of each step within the engineering design-process and the overall process. The questionnaire consisted of eleven open-ended questions constructed to gauge students' understanding. The questionnaire was read to students that had a learning disability or whom English was their second language. Student responses were then coded by the researchers into four categories of understanding of each part of the engineering design-process: complete understanding, partial understanding, no understanding, and does not answer. Students were allowed to use computers and iPads to complete the questionnaire with adequate class time. The researchers monitored the students to ensure they did not leave the Google Form to search the internet for answers to the questionnaire. These pre-questionnaires were given to students prior to any teaching of the engineering design-process in the current course. It was discussed that some students may have previous knowledge of the engineering design process, but students were not previously asked to recall this information at the time of the questionnaire.

To engage the students in the engineering design process, the researchers developed project-based units. These projects were designed to keep students engaged around a shared problem as they worked through the engineering design-process in teams. Prior to students starting their projects, instruction was provided on the sequential steps of the engineering design process, first using a short film called PBS Design Squad. The film showed children going through a problem-based scenario in which the engineering design process was used and discussed. During and after the film researchers implemented small group discussions around how the engineering design process was utilized by the teams in the film to increase their chances of success. These discussions were centered around how the students used the steps and whether or not their efforts yielded effective results. The film provided a simple introduction for the unit and gave students a shared experience to refer to when working on their own problem.

When students started the first lesson, they self-selected engineering teams and were asked to identify the problem or need based on the project at hand. Students were told to record all observations and ideas individually in their engineering notebooks. Next, students were instructed on the criteria and constraints of the project. They were told to keep these in mind as they continued to work through the process. Each day of the project began with short instruction on a step of the engineering design process, closely pertaining to where students were in their own process. Suggestions and examples relating to the film, watched at the start of the unit, were made for further reference and understanding. Student documentation of each step was emphasized and encouraged during all instruction. Forms of documentation kept by students in notebooks included: lists, sketches, photographs of research, notes, tables, research and conclusions. The researchers would review student engineering notebooks with a checklist

(Appendix C) as each step of the process was completed. This was done to make sure students were participating in the project and completing each step.

The students then researched the problem they identified, answering a set of questions created by the researchers. Students were allowed to research the problem using websites, books, articles and testing materials that were predetermined by the researchers. Students then proceeded to the design step in the engineering design-process. In the design phase, students were required to brainstorm a minimum of three different designs as a group, keeping the criteria and constraints in mind as they work. Sketches with notes on design features or materials to use were drawn in student notebooks so as to communicate their ideas to other group members and the instructor. To determine which design would adequately solve the problem, students were instructed on creating a decision matrix (Appendix F) that used the provided criteria and constraints to evaluate each solution. Students would then decide on a final design the group would pursue, moving onto the next stage. A range of tools and materials were provided for students to construct their ideas. The construction methods involved utilizing skills and knowledge students learned in previous lessons, so additional instruction was not needed for this step.

While students worked to complete these steps each day, the researchers performed observations over the different groups. The observations were recorded using the observational data collection sheet (Appendix D) and collected information on student conversations, thoughts, and group conclusions. Emphasis was provided on the aspects of the engineering design-process communicated by each group as they worked. Researchers were able to observe each group at stages of their design work, but not at all times. Upon completion of the class period and day, the researchers documented their reflections on the teacher reflection sheet (Appendix E) of the

quality of the lesson provided, student successes, student challenges and their overall involvement during the class period. Reflections emphasized student progress towards the learning objectives of the given engineering design process step. The observations (Appendix D) and reflections (Appendix E) also noted which step students were working on while being observed.

As students completed their designs they were instructed on appropriate testing methods. Based on their project, students needed to understand if their testing had to consist of recording measurements, other data, observations or physical implications. The test results needed to be evaluated for success based on the criteria and constraints, with students determining if success was achieved. If students did not achieve success, they were instructed to re-evaluate their solution and attempt to complete it with the remaining time allotted. When the due date was reached, all teams were provided a template for digital presentation (Appendix G). Students communicated their engineering design-process to their peers, providing examples of their work and stating whether or not their solution was successful. Each group was given time to present their work to the class after all groups completed the design work. Students were given time to discuss the success of each group and how they utilized the steps of the engineering design process in relation to one another. After all presentations were complete, students were asked to complete the post questionnaire (Appendix B). Class time was given to complete this using the same provided technology and observation as the pre-questionnaire.

Reporting Findings

Data collected in the study consisted of qualitative information collected through a questionnaire, checklist and teacher observations. The questionnaire consisted of 11 questions that asked students information about solving problems at various stages of the engineering design process.

All responses were in the form of a short answer. There was no prior teaching of the engineering design process in the course before the questionnaire was given. A total of 90 students submitted responses to the pre-questionnaire through a Google Form (Appendix B) accessed during class time. Students were then taught the use of the engineering design process through a project-based assignment where each step was implemented and taught as it was needed. As students worked on the assigned problem researchers kept observational logs of the student groups. Qualitative data gathered in the observation included what step the group was currently using and the language used in their conversations as they worked. Engineering notebook checklists were used to track if students documented the work needed for each step of the project. Researchers gathered additional qualitative data through a teacher journal reflection written upon the conclusion of class time or the teaching day. At the conclusion of the project the post questionnaire was administered and 79 student responses were recorded. Three students had moved to a different school during the treatment period and eight students were absent the day the final questionnaire was given. The researchers were able to utilize the results of the pre- and post-questionnaire, supplemented by the checklists and observations, to analyze student growth in understanding the use of the engineering design process.

Results of the questionnaires

In order to analyze the results of the questionnaire, provided as short answer statements, a coding system was developed to categorize answers. Responses were coded by their displayed understanding of the engineering design process in relation to the provided question. Table 1 shows the coding system developed to categorize students' responses to the questionnaire.

Table 1. Coding system for questionnaire responses

Coding System for Questionnaire	
Code	
0	Does not answer question
1	Vague answer, does not acknowledge EDP steps/process
2	Answer contains elements of EDP steps/process
3	Demonstrates clear/effective use of EDP steps/process

The coding enabled researchers to better analyze the data from each question equally across questionnaire. To identify the overall results of the questionnaire, the researchers determined the average score of each question in the pre- and post-tests. The averaged score of each question shows that large positive growth was achieved in questions three, four and five. Small positive growth was achieved in questions two, six, and 10. Marginal to no growth was shown in questions one, seven, eight, nine, and 11. Each question identifies different steps and knowledge of the engineering design process in no particular order. Figure 1 shows that measurable positive growth was made in several areas, but each question should be further analyzed within a group in order to make conclusions.

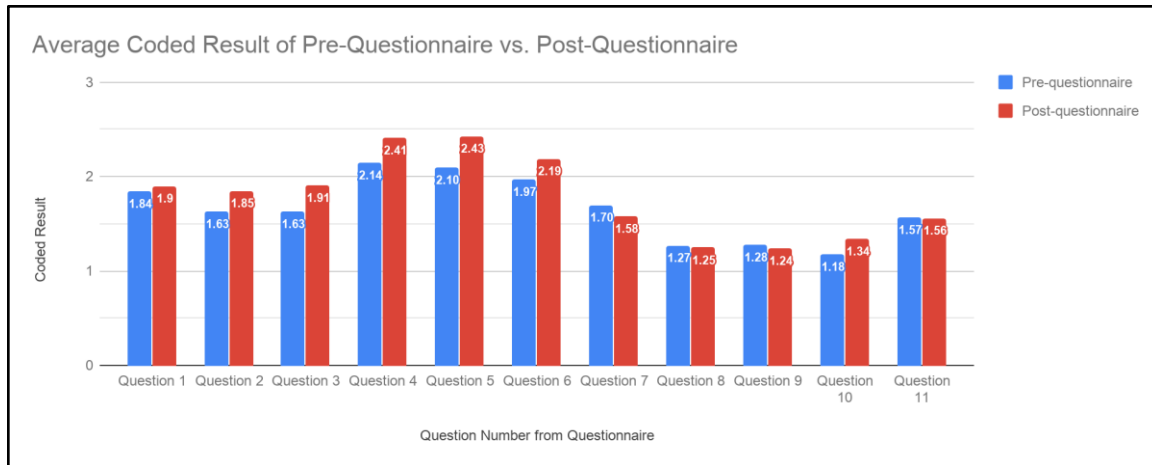


Figure 1. Average coded responses pre questions of pre- and post-questionnaire.

In a closer look at each question individually, questions three, four and five showed the largest amount of growth overall. Figures two-four break down the percentage of coded answers. When the percentages of these three questions are looked at closely they show a reduction in lower level responses of zero or one. This recurring condition shows growth for student answers as they move into coded two and three responses from the pre- to post-questionnaire. Question three analyzed student ability to describe different forms that design can take and process the step may consist of. In looking at question three individually, there was a decrease in code zero-two responses but a 12.4% increase in code three responses. This demonstrates a shift student understanding on how to describe what it means to design. Question four analyzes students ability to define when a person should utilize the engineering design process and produced similar results to the previous questions. Coded responses zero-two saw a decrease, with coded three responses seeing a 13.8% increase. Question five addressed what should be known prior to building a design and also saw a decrease in coded zero and one responses. Coded two and three responses saw an increase. A closer look at question five shows minimal coded zero and one responses, coded one responses seeing a dramatic drop in the post questionnaire. Over 90% of student responses in the post questionnaire showed student

understanding of best practices within the engineering design process for question five. This positive growth is well represented in the questionnaire results and will be further represented in the observational and reflection journal data.

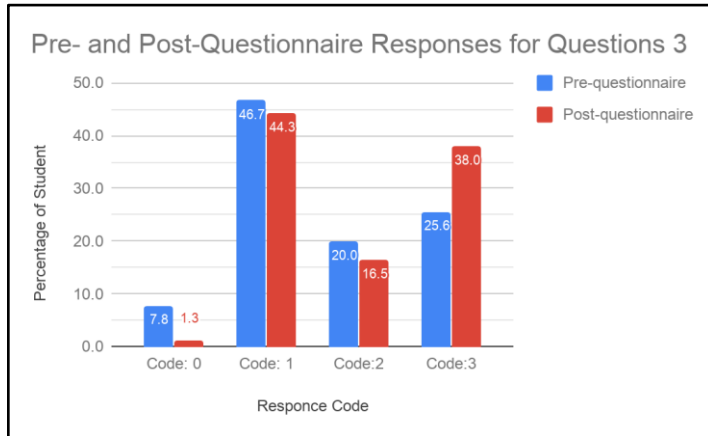


Figure 2. Pre- and Post-Questionnaire Responses for Question Three. “What does it mean to design?”

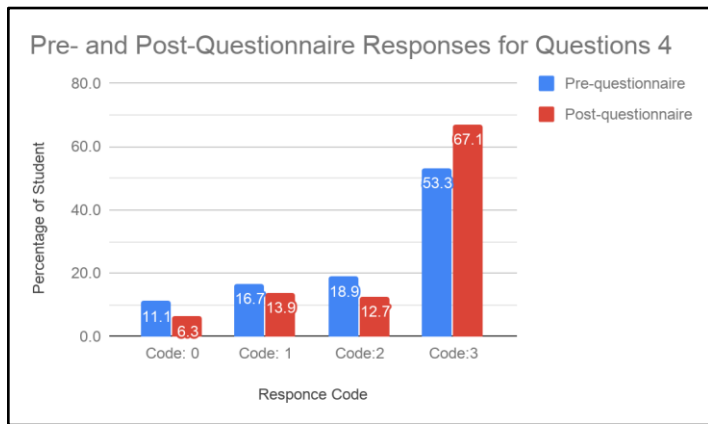


Figure 3. Pre- and Post-Questionnaire Responses for Question Four. “When might a person use a design process?”

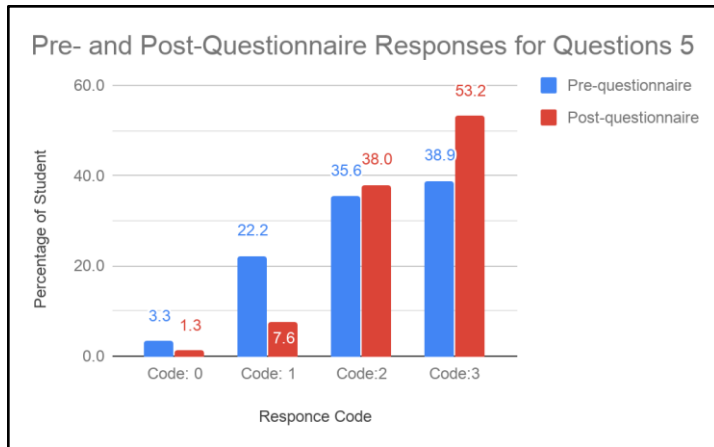


Figure 4. Pre- and Post-Questionnaire Responses for Question Five. “If you wanted to build something, what would be important to know before starting?”

The coded results from questions two, six, and 10 show a positive growth with a smaller average. In figure 1, the average coded score growth of questions two, six, and 10 are less than questions three-five. However, upon closer examination it can be found that the majority of the positive growth is shown in the coded two responses. In question two, the number of students writing a code three response increased by 8.7%. The percentage of students who provided a higher-level answer increased in each code level, showing growth in the overall student population. Questions six saw similar types of growth with coded answers written at a higher level of competency, seen in figure 6. The greatest growth within question six was seen in code two responses, which saw a rise of 9.5%. Code 1 responses decreased by 8.2%, which put over 91% of the student population in the code two and three response categories. Question 10 analyzed student understanding of how to select the best design from all generated ideas, a difficult task to measure. This question generated few code three answers, but still saw positive growth from pre to post. The largest growth was from code one to code two responses. Code two responses rose 12.7% while code one responses decreased 13.8%. This showed a change in understanding for many students in what was the most difficult concept to teach within the

engineering design process. The researchers believed the growth in these three questions to be deceiving when comparing the overall score mean. The growth per step coded score showed a more natural growth from a more expected basic level within the sampled age group.

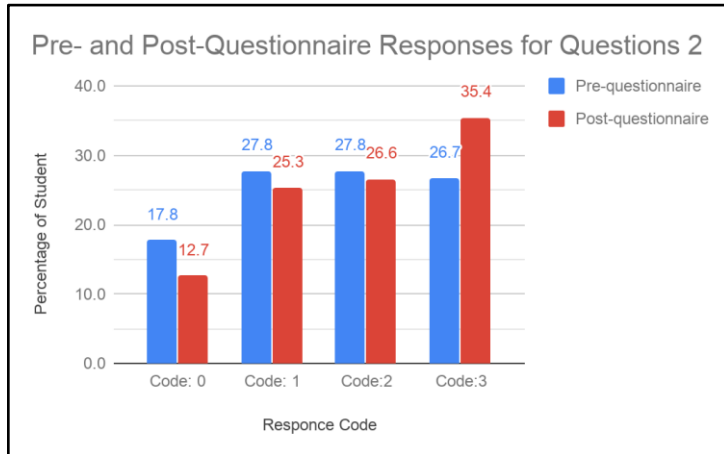


Figure 5. Pre- and Post-Questionnaire Responses for Question Two. “What do forms of research look like to you?”

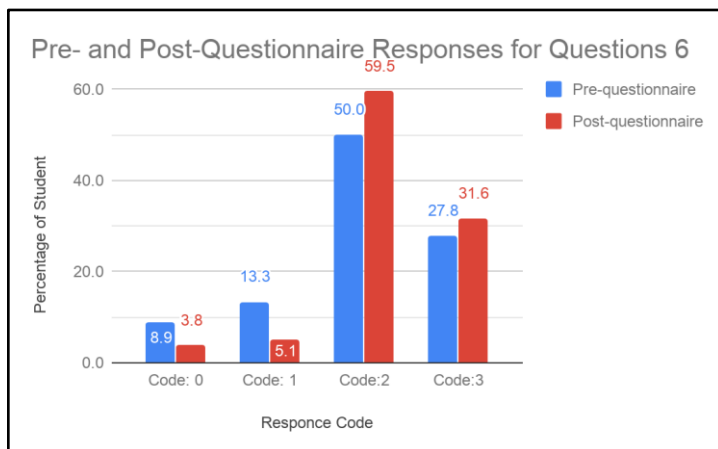


Figure 6. Pre- and Post-Questionnaire Responses for Question Six. “If you made something you were proud of, how would you show and tell people?”

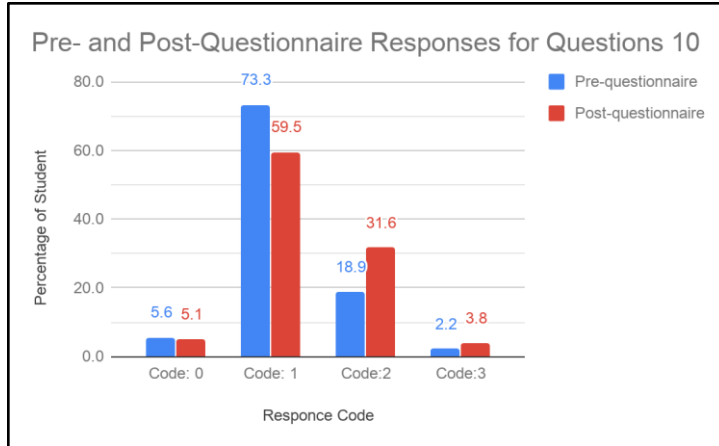


Figure 7. Pre- and Post-Questionnaire Responses for Question 10. “If you had several good ideas, how would you pick the best one?”

Our results for questions one, seven, eight, nine, and 10 showed marginal growth and some decline in student understanding. Question one showed marginal growth when comparing the students average per- and post-questionnaire results (See *Figure 1*). Looking closer at question one (*Figure 8*), students gained some partial understanding of what a person would need to know to solve a problem. Our results showed a decrease from the pre-questionnaire to the post-questionnaire in the percentage of students that short answers were coded zero or one. These students moved into the code two category, while code three results were unchanged. Looking at the coded responses for questions eight and nine (Figures 9 and 10) showed that there were no gains for these questions. The percentages for all four categories in questions eight and nine show either small gains or losses from the pre-questionnaire to the post-questionnaire. The largest percentage of students’ responses for both of these questions were code one showing that the students had little understanding of these concept both before and after the treatment. Students showed losses in codes two and three on the post-questionnaire results when asked to describe the difference between a model and a prototype (figure 12). The students performed better on the pre-questionnaire with 61.1% of students’ written responses coded a two or three

and on the post-questionnaire 50.7% of student responses were coded a two or three. This showed 10.4% of students had a loss.

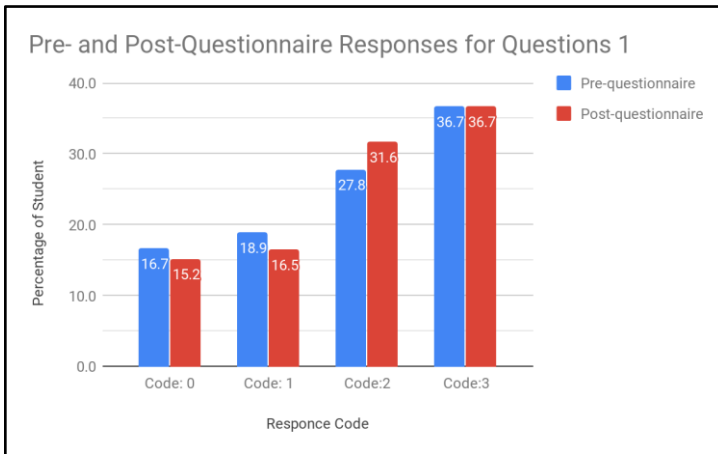


Figure 8. Pre- and Post-Questionnaire Responses for Question One. “What might a person need to know to solve a problem?”

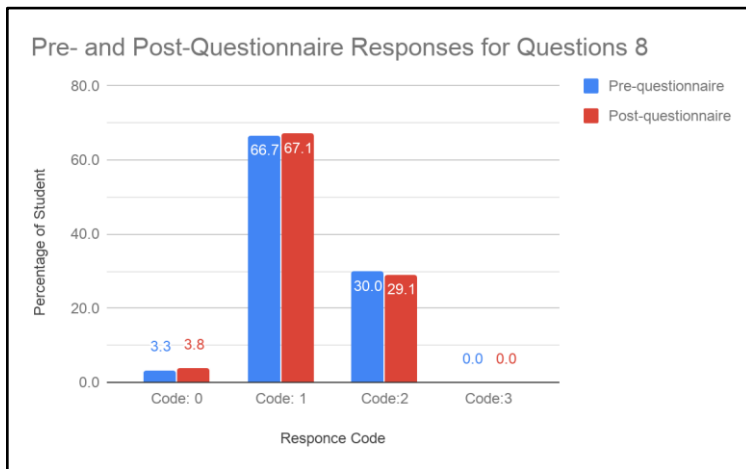


Figure 9. Pre- and Post-Questionnaire Responses for Question Eight. “Why would it be important to look at test results?”

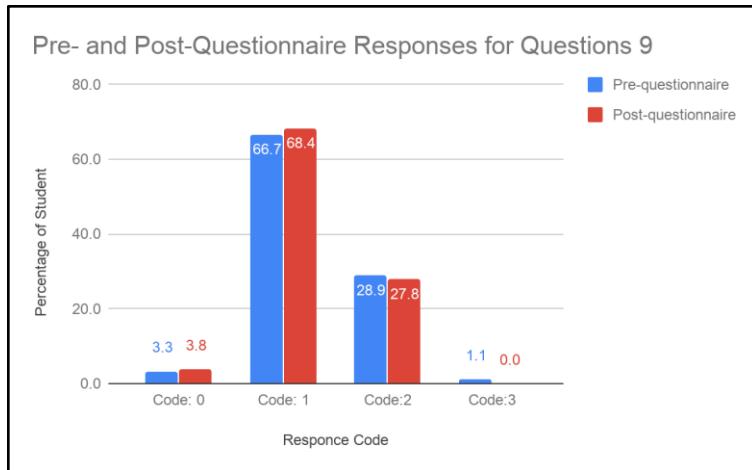


Figure 10. Pre- and Post-Questionnaire Responses for Question Nine. “How could a person come up with good ideas?”

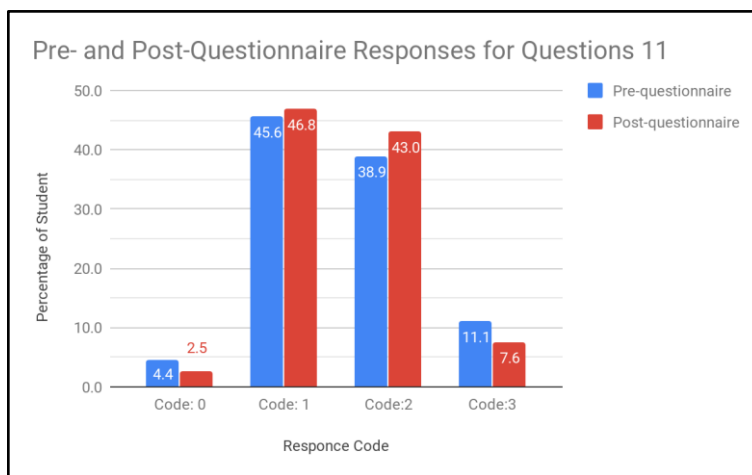


Figure 11. Pre- and Post-Questionnaire Responses for Question 11. “Describe what engineers do?”

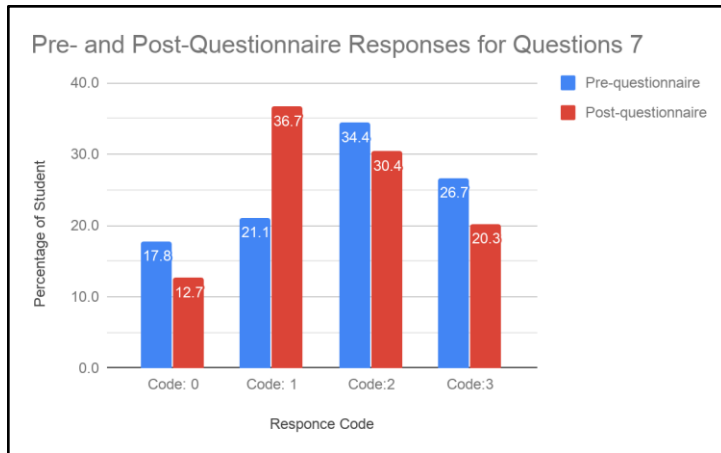


Figure 12. Pre- and Post-Questionnaire Responses for Question Seven. “Describe the difference between a model and prototype.”

Observations & Reflections

The researchers were able to make notable observations of students as they worked each day on the provided step of the design process. At the beginning of the unit students watched a film of children completing a design challenge, utilizing the design process in their work. The observation reports showed that groups were able to discuss their task at hand in relation to the students in the video, watched at the start of the unit. Students often made analogies of their progress to that of the groups in the movie. This shared experience allowed student to communicate with each other easier and provided a communal overview of the engineering design process. The researchers believe that this shared experience correlates with the improvement of code three responses for question four, “When might a person use a design process?”.

The first day of scaffolding implementation of the engineering design-process focused on understanding the problem, establishing criteria and constraints of the problem and the project as a whole. Students were observed documenting all the necessary information in their notebooks and expressing excitement to start the project designs the next day. The students’ documentation

of the criteria and constraints and the observations of the students show why there was an improvement for question 5, “If you wanted to build something, what would be important to know before starting?”. Researcher journals observed that students were inquisitive about future steps would be or directly referenced the next stage of the engineering design process. The next instruction day researchers taught on design development through brainstorming and research. Best practices for each grade level were provided and design targets identified for each class. Researchers observed a variety of communications and group activity in this stage as teams worked on their designs. A majority of groups lead discussions that included all team members contributing to design ideas. All students created sketches of at least one design in their notebooks. It was observed that many teams split research tasks among teammates to recovine at the end of class to compile what was learned. Teams communicated their design ideas via sketches, notes, researched examples and lists. Several teams were observed compiling different student designs on a shared team design. Researches noted in a journal entry that “It was apparent that students were thinking of the next couple steps ahead as they brainstormed and designed ideas. Many of the students commonly referenced the provided materials in their designs and how they could be utilized. Some students labeled the different elements of their design as a specific material. Other groups color coded their design materials using colored pencils.” The observations that the researchers made during the research and design phase of the engineering design-process along with the researchers’ journals, and the students’ notebooks show why the students had improvement in coded responses for question two, “What do forms of research look like to you?”, and question three, “What does it mean to design?”.

The next teaching points surrounded selecting the final design and beginning the build process. Researchers observed teams comparing and contrasting designs with the provided

criteria and constraints. There were analytical conversations held in the groups observed that showed student understanding of how to utilize the engineering design process in their effort to solve the problem. Students had the understanding to think ahead to their build and test stages, analyzing what designs or materials would work best. These observations of the students gave the researchers an understanding of why the students improved for question 10, “If you had several good ideas, how would you pick the best one?”. It was observed that teams were also getting acquainted with each other, identifying the strengths of specific teammates for the building stage. The next stage in the instruction was teaching students to test their designs, a simple intuitive task for the problem at hand. Instruction was emphasized on documenting testing results and re-analyzing for improvements to the design. Teams were observed referencing their previous work as testing results were collected. Teams analyzed if their designs worked as planned or if adjustments needed to be made. Students were seen looking at previous design work to see if another design implication would improve the results of the current prototype. To complete the project work, students were then instructed to communicate the results of their design via a presentation with the template provided. Researchers observed students utilizing technology to document their notebook work with pictures, providing authentic examples of their work. The majority of groups were able to communicate the timeline of their designed project in the presentation, demonstrating their understanding and knowledge of the engineering design process. The researchers believe that allowing students to present their findings explain the improvement in students responses for question 6, “If you made something you were proud of, how would you show and tell people?”. In many conversations among student peers and teacher to student, references were made to what would have improved a design or what the students would have done differently given the same problem again. These students demonstrated

understanding of how the engineering design-process would continue even after it had been completed once. The work observed within each team demonstrated overall growth in the understanding and knowledge of the engineering design process by the researchers. As the questionnaire results were analyzed, the reflection journals supported all areas of reported growth. These results are based on the observations that students and teams experienced growth within the engineering design process, and not that the quality of all designs were at a similar level.

The researchers believe that scaffolding the implementation of the engineering design process, with use of guided inquiry, was successful in helping students better understand the individual steps within the process. Students showed gains in six of the eleven questions on the questionnaire. These six questions coincide with identifying the problem, researching, designing and planning, communicating, and identifying when to use the engineering design process. Students did not perform well when asked to explain the importance of analyzing test results. The researchers believe that this was due to students not understanding the context of the question. When coding the students' responses, the researchers noticed many student answers talked about grades in school. One student wrote, "So you can see if you can make it to college/next grade." Another response was, "See if you got an A." The students also did not perform well on questions that asked the difference between a prototype/model and what engineers do in their work. After reviewing the teacher journals, the researchers noticed that neither one of these questions were covered in depth during the engineering design-process instructional treatment period. The researcher noted in their journals that some students may have been experiencing questionnaire fatigue or rushed through the questionnaire when noticing that other students had finished before them. This might explain the lack of growth for some of

the later questions. Some students may have had previous knowledge or teaching of engineering, but the population as a whole did not. Therefore, students' lack of improvement would not be expected.

Action Plan

The results of this action plan show that scaffolding instruction of the engineering design-process can have a positive effect on student learning. Students showed gains in their knowledge and understanding in several steps of the process. The most significant areas were in the designing step, when to use the engineering design-process, and defining the problem.

Typically, students are content with a small number of designs and do not communicate with others much about features of their ideas. As the students worked in groups and had to talk with one another about their designs it became apparent that the ideas within each group grew due to their team communication. This provided students with a more authentic experience of brainstorming within a group to come to a common conclusion or culmination of a final design. Students were able to critically analyze others' ideas and how to mix them with their own to develop a cumulative idea. Both researchers noted that the quality of ideas and work done by students was at a high level for the overall population. This occurred within the steps where student growth was identified and for the overall project. Researchers also noted that the majority of groups continuously recognized future steps as they planned their project. This increased group foresight could have been an additional contributing factor to the positive increase in quality work submitted. The forward thinking allowed students to troubleshoot or plan for problems that would occur in the steps after the current state.

Being able to identify where they were at in the engineering design-process and determine the steps ahead also helped students to indirectly reflect on the process as a whole. This hands-on approach to working through the problems helped to reinforce learning the steps, implementation and importance of utilizing the engineering design process. In the post questionnaire students were able to better describe and identify the use of the process and how

engineering design-process did help. This was measured in a shift from the number of lower coded responses to higher ones.

The researchers both fielded questions from students about how to know when to end the process or stop working if it is a continuous cycle. These inquiries identified further student understanding of how the engineering design process continues even after it appears to be complete. The research gathered has proven that measured growth in the majority of the student population deems scaffolding of design process implementation to have a positive effect on student learning and comprehension.

As a result of the of this research we will be scaffolding the instruction of the engineering design-process in the future. Besides students' increase in understanding the engineering design-process we noticed by using the scaffolding method students final products were better. There was also a higher level of student work completion for the project and the individual steps contained. Seeing the effectiveness of scaffolding on the overall engineering design process, we would focus on developing teaching best practices for each step within the process. There are many elements to learn in order to be proficient for each step. The overall process can be overwhelming for students and difficult for them to retain all the elements of each step. We believe that scaffolding the teaching of key components of each step and assessing students after the instruction would lead to a better understanding of where students struggle. The researchers would also format the assessment differently. We believe that students had some confusion while completing our assessment. The researchers would focus on the wording of the questions to make sure students understood the context within the engineering design process they were being asked.

The engineering design process can be implemented in a variety of classroom settings or project units. There are numerous directions in which this research could be continued to understand how students use, comprehend and grow with the process. This research was done in a project-based learning unit, but a study could be done with similar age groups taking place both with and without a project for students to work on. A similar study could also be done with or without a hands-on learning project. Further aspects could be analyzed in a similar study looking into the difference of male and female achievement or individual vs. team-based projects. Studies could also analyze the use of STEM concepts and the student perceptions of their utilization of those concepts. These different research ideas could be performed at various grade and skill levels in multiple curricular areas to gather a larger variety of data.

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Appendix A

The Effects Scaffolding Implementation and student understanding of the Engineering design process within STEM project-based learning.

Parental Permission Form

2/20/18

Dear Parents,

In addition to being your child's Technology Education teacher, I am a St. Catherine University 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 scaffolding instruction of the engineering design process because research has shown that scaffolding is a way for students to increase their voice, autonomy, and active engagement in problem solving, inquiry, and the design projects.

In the coming weeks, I will be engaging students in the design process as a regular part of my project-based units within our engineering curriculum. All students will participate as members of the class. In order to understand the outcomes, I plan to analyze the data obtained from the results of scaffolding lessons on project-based learning to determine student growth, understanding and use of the engineering design process. The engineering design process is a step-by-step process that engineers follow when developing a solution or product that solves a problem or need. The steps within the engineering design process include, identifying the problem or need, researching, planning and designing, building, testing, and redesigning based on information gathered from testing. All strategies implemented and assessments given are part of normal educational practice.

The purpose of this letter is to notify you of this research and to allow you the opportunity to exclude your child's pre and post-test results, engineering notebooks, and the written observations of your child's conversations and work they conduct within their groups I collect 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 2/10/18. Note that your child will still participate in the lessons 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 work to determine the effectiveness and retention of using the engineering design process with STEM project-based learning units for students.
- 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. Catherine University 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, 952-496-5752, ext 4344. You may ask questions now, or if

you have any questions later, you can ask me, or my advisor David Stricker through email dstricker@stkate.edu, 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(s), 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.

Chris Lyons

Date

OPT OUT: Parents, in order to exclude your child's data from the study, please sign and return by 2/27/18

I do NOT want my child's data to be included in this study.

Signature of Parent/Guardian

Date

The Effects Scaffolding Implementation and Student Understanding of the Engineering Design Process within STEM Project-Based Learning.

Parental Permission Form

1/29/2018

Dear Parents,

In addition to being your child's Engineering teacher, I am a St. Catherine University 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 teaching the engineering design process by breaking it into smaller parts and teach each part separately because research has shown that breaking up a big process into smaller parts is a way for students to increase their voice, autonomy, and active engagement in problem solving, inquiry, and the design projects.

In the coming weeks, I will be engaging students in the design process as a regular part of my project-based units within our engineering curriculum. All students will participate as members of the class. In order to understand the outcomes, I plan to analyze the data obtained from the results of scaffolding lessons on project-based learning to determine student growth, understanding and use of the engineering design process. All strategies implemented and assessments given are part of normal educational practice.

The purpose of this letter is to notify you of this research and to allow you the opportunity to exclude your child's pre and post-test results, engineering notebook, and observations of your child I collect 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 2/9/2018. Note that your child will still participate in the lessons 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 work to determine the effectiveness and retention of using the engineering design process with STEM project-based learning units for students.
- 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. Catherine University 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 or are unsure about the process, please feel free to contact me, 651-744-7663 or at jeffrey.kohoutek@spps.org. You may ask questions now, or if you have any questions later, you can ask me, or my advisor David Stricker through email drstricker@stkate.edu, 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(s), 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.

Jeff Kohoutek

Date

1/29/2018

OPT OUT: Parents, in order to exclude your child's data from the study, please sign and return by 2/9/2018

I do NOT want my child's data to be included in this study.

Signature of Parent

Date

Appendix B

QUESTIONS	RESPONSES
<h3>Engineering Design Process Questionnaire</h3> <p>Form description</p>	
What might a person need to know to solve a problem?	*
Short answer text	
What do forms of research look like to you?	*
Short answer text	
What does it mean to design?	*
Short answer text	
When might a person use a design process?	*
Short answer text	
If you wanted to build something, what would be important to know before starting?	*
Short answer text	

If you made something you were proud of, how would you show and tell people? *

Short answer text

Describe the difference between a model and prototype. *

Short answer text

Why would it be important to look at test results? *

Short answer text

How could a person come up with good ideas? *

Short answer text

If you had several good ideas, how would you pick the best one? *

Short answer text

...

Describe what engineers do. *

Long answer text

Appendix C

Engineering Notebook Checklist

Steps or Process	3 pts	2 pts	1 pts	0 Pts
Problem	<ul style="list-style-type: none"> <input type="checkbox"/> Problem is stated clearly <input type="checkbox"/> Research on background of problem is documented <input type="checkbox"/> Constraints and Criteria identified 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing one component 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing two components 	No Components
Design/Plan	<ul style="list-style-type: none"> <input type="checkbox"/> Design ideas documented <input type="checkbox"/> Variability among designs <input type="checkbox"/> Labeled sketches and descriptors. 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing one component 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing two components 	No Components
Build	<ul style="list-style-type: none"> <input type="checkbox"/> Meets all criteria <input type="checkbox"/> Meets all constraints <input type="checkbox"/> Performs all parts of task as required 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing one component 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing two components 	No Components
Test/Evaluate	<ul style="list-style-type: none"> <input type="checkbox"/> Data from test is collected <input type="checkbox"/> Need for improvement/ changes is reflected on <input type="checkbox"/> All results documented 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing one component 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing two components 	No Components
Communicate	<ul style="list-style-type: none"> <input type="checkbox"/> Progress of idea from start to finish is shown. <input type="checkbox"/> Generated idea is communicated in a clear and concise manner. <input type="checkbox"/> Evaluates solution against identified criteria & constraints. 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing one component 	<ul style="list-style-type: none"> <input type="checkbox"/> Missing two components 	No Components

Appendix D

Observational Data Collection Sheet

Circle Group Number: 1 2 3 4 5 6 7 8

Date: _____

Periods/Class: _____

Circle part of the Engineering Design Process:

Identifying the problem or client need	Researching	Plan and Design	Create/Build	Test	Improve
--	-------------	-----------------	--------------	------	---------

Record students' conversations

Circle Group Number: 1 2 3 4 5 6 7 8

Circle part of the Engineering Design Process:

Identifying the problem or client need	Researching	Plan and Design	Create/Build	Test	Improve
--	-------------	-----------------	--------------	------	---------

Record students' conversations

Appendix E

Teacher Journal Reflection Sheet

Journal Reflection

Date:	Class: Time:
Lesson/Activity: What type of activities did I provide for the students?	Area of EDP Students are working on.
Reflections on activity taught. Did these activities seem to help students progress towards or achieve the defined learning objectives of the unit?	Observations of students while lesson is taught. What successes and challenges did students have towards meeting the learning objectives?
	Other notes and observations.

Appendix G

Presentation Template

Engineering Design Process Project

By:

Problem:

Click to add text

Design

Click to add text

Plan

Click to add text

Final Design Choice

Click to add text

Build

Click to add text

Test

Click to add text

Evaluate

Pro's of Design

-

Con's of Design

-