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A QUASI-EXPERIMENTAL STUDY OF MIDDLE LEVEL STUDENT ENGINEERING UNDERSTANDING PRE-AND POST-TREATMENT

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THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Education at the University of Kentucky

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ABSTRACT OF THESIS

A QUASI-EXPERIMENTAL STUDY OF MIDDLE LEVEL STUDENT ENGINEERING UNDERSTANDING PRE- AND POST-TREATMENT

This qualitative quasi-experimental study analyzed middle-level students' understanding of engineering before and after instruction. Students from four teachers were examined. Before and after instruction, all students completed the Draw an Engineer Test (DAET) and the Views of Nature of Engineering (VNOE) survey. Additionally, sixteen students (eight girls and eight boys) from each group (Treatment and Comparison) were interviewed before and after instruction. Findings revealed that after instruction (1) many students viewed engineers as makers/builders/workers (just as they did pre-instruction), however, the percentage of students who listed engineers as inventors, designers, and creators increased; (2) fewer students from both groups noted they had heard about the engineering design process or had considered being; (3) the interviewed Treatment students were more knowledgeable about engineers than were the interviewed Comparison students. This study is important as it is one of the first studies to examine student understanding of engineering after receiving a science-based engineering design unit, and it found the total understanding to require improvement.

KEYWORDS: Engineering, Education, Design, Understanding, Middle Level

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DEDICATION

I dedicate this paper to those who have supported me during my graduate education. This includes my parents, Jerry and Michelle Driessen, my brother Aaron Driessen, and my dear friend Matthew Myers.

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A special thank you to Dr. Jennifer Wilhelm for helping guide me through the process of earning a Master's degree and developing this thesis. I acknowledge Dr. Merryn Cole for all of her advice and expertise concerning the chemistry-based engineering design unit used in my thesis work. Dr. Molly Fisher and Dr. Suzanne Smith were excellent Master's committee members and provided insight pertinent to this paper.

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Introduction

This study investigates the extent to which engineering understanding changes among middle-level science students enrolled in classes that receive a chemistry-based engineering design unit as compared to middle-level science students enrolled in classes with teachers whom may choose what they teach during that same time period. This investigation is especially important given the national stress on improving engineering education (Olson & Riordan, 2012; Committee on STEM Education of the National Science and Technology Council, 2018) in order to prepare students to address the prominence of science, engineering, and technology in their everyday life, provide solutions for pressing and future problems, and stop the further decline of the position of the United States in the global economy (National Research Council; 2012). In this climate of stressing the importance of integrative STEM Education, The Next Generation Science Standards (NGSS Lead States, 2013) were created, and they are the first set of national education standards to include science and engineering practices and engineering as a discipline. Much research has been conducted to assess student understanding of science or math after implementation of a science or math-based engineering design unit (Huang, Brizuela, & Wong, 2008; Guzey, Moore, & Harwell, 2016; Cole, 2017; Schnittka, Bell, & Richards, 2009), however, research has rarely been conducted to gauge a possible change in student engineering understanding after receiving the same type of unit. This investigation aims to add to the scant amount of research conducted in this area by implementing a chemistry-based engineering design unit called Chemical Reactions Engineered to Address Thermal Energy Situations (CREATES; Wilhelm, Wilhelm & Cole, 2019), to one student group (treatment) while leaving another group to its lessons as usual (Comparison) and measuring the changes in understanding. Since the middle level (students approximately aged 11-14 years) has been identified as a crucial time for either inspiring or discouraging student interest and participation in mathematics and science as well as their interest in a career (Brophy, Klein, Portsmore, & Rogers, 2008; Tai, Liu, Maltese, & Fan, 2006; Cummings and Taebel, 1980), we used middle level students as our research population of interest. Specifically, three research questions were explored in this paper: 1) How do middle level science students view engineers and engineering before and after instruction?; (2) Do middle level science students who experienced a chemistry-based engineering design unit have a different understanding of engineers and engineering than the Comparison students who experienced lesson plans as usual?; and (3) How do teacher understandings of engineering and engineers compare to their students?

Background

Engineering in the Next Generation Science Standards

The Next Generation Science Standards (NGSS) are the first set of national education standards to have incorporated engineering into the K-12 curriculum. These standards identify specific performance expectations (PEs) the students are to learn in each grade band (K-2, 3-5, 6-8, and 9-12). There are three dimensions to teaching the science PEs designated by the NGSS: (1) science and engineering practices, (2) disciplinary core ideas (DCIs), and (3) cross cutting concepts. The science and engineering practices "describe what scientists do to investigate the natural world and what engineers do to design and build systems" (NGSS Lead States, 2013, p. 48). The DCIs represent key science ideas that are important across multiple science or engineering domains. The crosscutting concepts establish connections between the four domains of science explored in the NGSS (physical science, life science, earth and space science, and engineering design).

The subject of engineering is incorporated through three DCIs and eight science and engineering practices in the NGSS. The engineering DCIs include: (1) Defining and delimiting an engineering problem; (2) Developing possible solutions; and (3) Optimizing the design solution. The eight science and engineering practices include: (1) Asking questions (science) and defining problems (engineering); (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analyzing and interpreting data; (5) Using mathematics and computational thinking; (6) Constructing explanations (science) and designing solutions (engineering); (7) Engaging in argument from evidence; and (8) Obtaining, evaluating, and communicating information (NGSS Lead States, 2013). Each of these eight practices can be used for scientific inquiry or engineering design and should be included within students' education. According to the NGSS, the goal of a learning activity is what defines the practice. If the goal is to answer a question, then students are doing science, but if the goal is to define and solve a problem, then the students are doing engineering (NGSS Lead States, Volume 2 Appendixes, 2013, p.49).

The Engineering Design Process

The term engineering design process (EDP) will be used frequently in this paper, so it is important to define. According to the National Research Council (NRC; 2012), the EDP represents a variety of practices used by engineers to solve problems. Specifically, these practices “incorporate specialized knowledge about criteria and constraints, modeling and analysis, and optimization and trade-offs” (p. 204). Although Engineering is Elementary (EIE; 2018) presents the EDP with five components (Ask, Imagine, Plan, Create, and Improve) and NASA Education presents the process with six components: Ask, Imagine, Plan, Create, Test or Experiment, and Improve (National Aeronautics and Space Administration, 2017), the NGSS are the commonality between the two student groups in this study, so the NGSS definition will be used here.

The NGSS defines the engineering design as three iterative steps: (1) Defining and Delimiting the Engineering Problem, (2) Developing Possible Solutions, and (3) Optimizing the Design Solution. Together, these three steps address engineering design according to the grade band. For example, for grades K-2 the “emphasis is on thinking through the needs or goals that need to be met, and which solutions best meet those needs and goals” (NGSS Lead States, Appendix I, p. 3). The EDP for Grades 3-5 has the students build on the idea of defining a problem to add more rigor to identifying and testing solutions and concentrate on the iterative aspect of the process. As for Grades 6-8, students connect problems to the “larger context within which the problem is defined, including limits to possible solutions” (NGSS Lead States, Appendix I, p. 4).

Review of Literature

Student Understanding of Engineers and Engineering

Studies have shown low-middle level student interest in becoming an engineer (Driessen, Dunn, Sallah, Wilhelm, & Cole, 2018; Katz, 2009). Specifically, Katz’s (2009) research found 85% of 1,277 students, ages 8-17, were not interested in a career in engineering. Further, Driessen et al. (2018) demonstrated that 60% of approximately 200 seventh-grade students have never thought about being an engineer.

Even after instruction, student attitudes toward engineering do not always improve. For example, Martinez Ortiz et al. (2018) found that rising 6^{th}-8^{th} graders' (*N*=65) attitudes toward mathematics, science, and engineering as well as their motivation to become an engineer was not statistically significantly different after attending a weeklong summer camp (6 hours a day for 6 days) that focused on sparking student interest in engineering as a career and developing student content knowledge in science and mathematics content. Conversely, Blanchard et al. (2015) investigated the impact of a year-long afterschool design-based program on a diverse group of middle school students (i.e. about 2,200 students split among three middle schools). Findings indicated that the afterschool program participants were initially more interested than their non-involved schoolmates in engineering careers, and the program participants gained an even greater interest over the academic year.

Other studies have shown that middle level students have an underdeveloped understanding of engineering and engineers. For example, Knight & Cunningham (2004) found high percentages of middle level students categorized engineers as builders and fixers. Fralick et al. (2009) similarly found middle level students frequently perceived engineers as performing manual labor outdoors. Jordan and Snyder (2013) investigated middle school student understanding of engineering understanding among the participants of afterschool engineering clubs and how the experiences within the club affect their understanding, and findings suggested that many of the study subjects had limited conceptions of engineering. Additionally, Driessen et al. (2018) demonstrated that middle level students still hold naïve views of engineering as they largely viewed engineers as makers/fixers/workers rather than problem solvers or thinkers.

Teacher Understanding of Engineering

It is important to consider teacher understanding of engineering because, ultimately, a teacher's content understanding can affect classroom understanding (Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013; Anderson & Mitchner, 1994). Yaşar et al. (2006) developed a survey instrument to assess K-12 teachers' understanding of engineering as well as their familiarity with teaching design, engineering, and technology. The survey findings revealed female teachers rated the importance of design, engineering, and technology higher than did their male counterparts, and that elementary teachers were the least likely to teach design, engineering, and technology. Additionally, it was revealed that teachers with moderate experience were the most open to learning more about design, engineering, and technology. Overall, teachers lacked confidence in their ability to teach design, engineering, and technology, and they held stereotypes about the skills needed to be an engineer.

Hynes, (2012) investigated *What subject matter and pedagogical content knowledge do middle school teachers use as they teach the engineering design process?* Her research studied how six teachers (ranging from 5th to 8th grade level instructors) explained the different steps of the engineering design process to their classes as applicable to a LEGO robotics engineering design challenge. Of the eight steps of the engineering design process, only one was understood at a high rating (did not simply name the step and read the description verbatim from the EDP handout, but instead went beyond this by discussing the process of completing the step, providing rationale for the step, and possibly illustrating the step with a real-world example) by all six of the teachers, and this was step 5: construct a prototype. Of the other steps, 8 (redesign) was understood by 3 of the six teachers at a high level, steps 6 (test and evaluate solution) and 7 (communicate the solution) were understood by two of the six teachers at a high level, steps 1 (identify a need or problem) and 2 (research need or problem) were understood by only one teacher of the six at a high level, and steps 3 (develop possible solutions) and 4 (select best possible solution) were not understood by any of the six teachers at a high level.

Deniz, Yesilyurt, Kaya, and Trabia (2017) measured elementary teachers' Views of Nature of Engineering (NOE) before and after a 3 day, 6 hour-a-day professional development program. The program included a 30-minute lecture about engineering in the Next Generation Science Standards, an introduction to the engineering design performance expectations of grades K-2 and 3-5, a 1-hour lecture introduction to the engineering design process, a lecture detailing the engineering design process of constructing a soda can crusher, and an engineering design challenge where the participants experienced the construction of soda can crushers in groups of 3 or 4. Results suggested NOE views improved for, namely, the engineering design process, creativity, and socio-cultural aspects.

Engineering Design Research

Huang, Brizuela, and Wong (2008) developed Building Math which consists of three middle school instructional units that integrate inquiry-based mathematics investigations with engineering design challenges in 6th and 8th grade classrooms. Specifically, in one unit, the 6th grade students concentrated on temperature changes of a warmed mannequin placed in a -15 degrees Fahrenheit environment while the 8th graders worked on a different unit that focused on temperature changes of a chilled malaria medicine that was then placed in an Amazonian environment of 98 degrees Fahrenheit. The 6th graders were to analyze orders of differences using the numerical values from a table and then extend a graph curve to recognize rates of change, while 8th grade students were to relate slope to rate and observe that relative change in slope indicates relative range in rate. After these investigations with temperature change, the sixth graders were to design the most cost-effective, less than 2 cm thick coat for the mannequin that kept its temperature above 65 degrees for 30 seconds while the 8th graders were to design a cost-effective, rugged and protective medicine-carrier that would keep the malaria medicine between 59 and 86 degrees Fahrenheit for 2 hours while in a 98 degree Fahrenheit environment. The researchers reported their main finding as: “when engaged in Building Math design challenges, middle school students at different grade levels use algebraic reasoning when analyzing changing rates of an exponential function, interpret slope in a meaningful context, and use a mathematical model to make reasonable predictions. They then use this understanding to inform their engineering designs to meet the criteria and constraints of the challenge (p. 17).”

According to Douglas, Moore, Johnston, and Merzdorf (2018), assessing the problem solving and critical thinking skills of a student in engineering is a challenge for teachers and researchers. However, when 5th and 7th graders (N=47) wrote reflections on what they had learned concerning engineering design practices, they provided evidence of improved engineering design understandings. This demonstrated written reflections may be an effective tool for evaluating student understandings of engineers.

Guzey, Moore, and Harwell (2016) studied 48 teachers participating in a year-long professional development program on STEM integration. Those teachers designed 20 new 4th-8th grade STEM curriculum units that integrated an engineering challenge (where students developed technologies to solve the challenge), grade level appropriate mathematics, and one of three science content areas (i.e. life science, physical science, or earth science). All of these units were assessed, and findings showed that the context or the engineering design activities in the STEM units concerning physical science were more engaging and motivating for students when compared to those of the life science or earth science based STEM units.

Theoretical Framework

Engineering Defined

This thesis investigates research questions that evaluate student understanding of engineers and engineering. In defining these terms, Karatas, Micklos, & Bodner (2011) noted there is little consensus concerning what the Nature of Engineering (NOE) actually is, so the literature was first reviewed. Table 1 demonstrates the differing and many definitions of engineers and engineering.

Table 1. *Various definitions of Engineers or Engineering (Driessen et al., 2018, p. 561)*

Authors	**Term**	**Definition**
Alon, 2003	Engineer versus tinkerer	Engineers plan structures in advance and draw up blueprints. A tinkerer puts together odds and ends in different ways until they come together in a functional way.

Davis, M., 1991	Engineers	"Engineers hold safety, health and welfare of the public in high regard as they 'handle things'" (Davis, 1991, p. 152).
Karatas et al., 2011	Engineering	Engineering requires analytical thinking. Engineering aims to meet the needs of the population.
Smith and Truxal, 1986	Engineering	Engineering is used to solve problems through the use of previous knowledge and a system of investigation. Engineering involves design and the formation or maintenance of complex systems.
Nguyen, D., 1998	Engineering	"Engineering is a profession directed towards the application and advancement of skills based upon a body of distinctive knowledge in *mathematics*, *science* and *technology*." (Nguyen, 1998, p. 65).
Capobianco et al., 2011	Engineers	Engineers integrate skills and knowledge in order to come up with solutions to problems.
National Research Council Committee on Theoretical Foundations for Decision Making in Engineering Design, 2001	Scientist versus Engineer	"A scientist studies what is, whereas an engineer creates what never was." (National Research Council Committee on Theoretical Foundations for Decision Making in Engineering Design, 2001, p. 1)

Using Table 1, the following definition of engineering and engineers was created in a previous study (Driessen et al., 2018). This definition was adapted by removing maintenance from the actions of engineering, and this newly adapted definition will be used as a lens to view the results of this study:

"Engineering is the design and improvement of ideas, systems, and products through the use of prior knowledge, mathematics, science, and technology; An engineer problem-solves and innovates to advance the community around them and fulfill a human need" (p. 561)

NGSS Middle Level Engineering Standards and Practices

As previously mentioned, science and engineering practices, crosscutting concepts, and engineering disciplinary core ideas (DCIs) are included in the NGSS, but – to be more specific about the DCIs and practices addressed at the middle level – this section frames what middle level students should be learning concerning engineering since this group encompasses our study population (7th graders). Specifically, middle school students should be able to (1) define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions (MS-ETS1-1); (2) Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem (MS-ETS1-2); (3) Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success (MS-ETS1-3); and (4) Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved (DCI MS-ETS1-4), according to the NGSS performance expectations (NGSS Lead States, 2013).

At the middle school level, there are four science and engineering practices, three engineering DCIs (previously addressed), and one crosscutting concept tied to these four PEs. The four science and engineering practices are as follows:

1. Asking Questions and Defining Problems: Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.

- Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1)

2. Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4)

3. Analyzing and Interpreting Data: Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3)

4. Engaging in Argument from Evidence: Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world.

- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2; NGSS, 2013)

The related crosscutting concept (CC) is: Influence of Science, Engineering, and Technology on Society and the Natural World. This CC conveys that (1) All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment (MS-ETS1-1) and (2) The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions (MS-ETS1-1).

This information will be referred to when framing the findings of this study, considering what the middle level students should know according to the NGSS.

Implemented Engineering Units

The Save The Penguins (STP; Schnittka, Bell, & Richards, 2010) engineering design curriculum was implemented by both of the Comparison Teachers. This unit focuses on educating students about the impact that burning fossil fuels has on the global temperature and, ultimately, the lifeforms that inhabit this Earth – namely penguins. The unit challenges students with an engineering design task to “save” them by designing energy-efficient homes for ice cube penguins. This is ultimately accomplished by having students view and interact with a series of teacher-directed demonstrations concerning energy transfer and then having the students “test materials for their ability to slow thermal energy transfer in order to keep the ice penguins cool. After testing materials**, students build** their penguin homes, and then see how well the dwellings keep the penguin shaped ice cubes from melting in a test oven” (p. 83). After students have built and tested their dwelling, the curriculum calls for them to evaluate the design of each dwelling by considering questions such as “Which design features were best at preventing radiation from the heat lamp from penetrating the dwellings?” and “Which design features were best at preventing the convection of hot air moving?” (p. 88). If time allows, the curriculum suggests having students reevaluate their designs in order to improve their dwelling.

Schnittka, Bell, and Richards (2009) implemented the STP curriculum, over 7 class periods, to 71 advanced-level eighth grade students over three different classes all taught by the same teacher. One class received the engineering design component from the STP curriculum, but they did not receive the demonstrations that usually precede the design challenge. Another class received the demonstration component of the STP, but they did not receive the engineering design challenge. A third class received both the engineering design challenge and the demonstrations (prior to the challenge). Findings indicated all three of the classes gained statistically significant knowledge concerning heat transfer. The two classes who participated in the engineering design demonstrated statistically significant gains in engineering attitudes based on the Attitudes Toward Engineering Survey (ATES; An eight item survey that lists questions and prompts such as *engineering would be a highly interesting profession for me*; *engineers design things that are practical and useful*; and *engineering skills are useful in everyday life*). This research demonstrates that while engineering design can improve student attitudes toward engineering, it alone does not suffice to promote meaningful conceptual change in science understanding. Therefore, well-crafted and research-based demonstrations are necessary, too, in order for students to undergo/experience/yield/show substantial gains in scientific understanding.

Chemical Reactions Engineered to Address Thermal Energy Situations (CREATES) is a project-based-instruction chemistry based engineering design unit (Wilhelm, Wilhelm, & Cole, 2019) that was has been used with the Treatment group. This unit focuses on teaching chemical reactions, the thermal energy of those reactions, and the Law of Conservation of Mass, around the Next Generation Science Standards. Specifically, the unit concentrates on the driving question: “How can I use chemical reactions to keep me comfortable?” (p. 111) through the incorporation of the following performance expectations: (1) MS-PS1-2 Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred; (2) MS-PS1-5 Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved; and (3) MS-PS1-6 Undertake a design project to construct, tests, and modify a device that either releases or absorbs thermal energy by chemical processes (NGSS Lead States, 2013). This unit also allows students to employ the engineering design process to create their own hot or cold pack based upon what they learned from the unit lessons. Specifically, the language used for the design project is “**building** a hot or cold pack” (p. 138). Spring boarding from that project, students ask their own sub-driving question which they investigate. Examples of such questions asked in the past have included:

> “How does using chemical energy for heating (or cooling) compare to other kinds of energy? What kinds of chemical reactions are more useful than others for keeping a person at a comfortable temperature? How is the amount of heat given off (or consumed) by chemical reactions measured? What temperature ranges are ideal for human comfort? How do engineers design heating or cooling devices?

How do chemical reactions in my body regulate temperature? How do engineers decide which factors are most important when they cannot meet all design demands? (p. 113)"

The CREATES unit has been taught to middle-level students in the past. Findings demonstrated that students significantly increased their understanding of the particulate nature of matter when experiencing CREATES. Additionally, a significant positive correlation between the understanding of the particulate nature of matter and spatial thinking was found for both middle school students and their teachers (Cole, 2017). However, this unit has never been used in research involving the investigation of changing engineering understanding before now.

Views of Nature of Engineering (VNOE)

The VNOE (Deniz, Yesilyurt, Kaya, & Trabia, 2017) is an 11-item questionnaire adapted from the Views of Nature of Science Questionnaire Version C (VNOS-C; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) to assess elementary teachers' Nature of Engineering (NOE) views rather than their Nature of Science (NOS) views. The VNOE was created using a framework including NOE aspects and their descriptions by modifying agreed-upon NOS aspects (Lederman, 2007) and the Next Generation Science Standards (NGSS Lead States, 2013). Finally, the VNOE was approved by a panel of 6 professors from diverse sub-disciplines of engineering, such as mechanical, electrical, computer, civil, and environmental to indicate to what extent they agree with the NOE aspect descriptions. Although this questionnaire was created with a scoring rubric, this was not used in this research. Instead, the focus was placed on simply elucidating and categorizing answers concerning students' understanding about engineers and engineering including their definitions of engineering, differentiation between engineering and other subjects, and thoughts of engineering as a career choice.

Draw an Engineer Test (DAET)

Knight and Cunningham (2004) used the DAET to collect students' images of engineers in order to assess students' ideas about engineering before and after intervention. This survey allows students to describe their knowledge about engineers and engineering through written and drawn responses. The Knight and Cunningham (2004) questionnaire contains five questions and the prompt: “Draw a picture of an engineer at work” above a 2.5 inches x 7.0 inches rectangle for drawing (p. 3). The version used in this research only includes the prompt, albeit slightly different (i.e. “draw a picture of an engineer”), and the rectangle for drawing. The drawing space is then followed by lines for explaining the drawing. However, there are no questions included.

Research conducted by Knight and Cunningham (2004) demonstrated that of 253 Draw an Engineer Tests (as drawn by 6^{th}-12^{th} graders), 52.5% represented building/fixing, 32.0% represented designing, 28.9% represented images of products of mechanical engineering (i.e. cars, engines, machines, robots, rockets, airplanes), 16.6% represented images of products of civil engineering (i.e. bridges, roads, buildings, houses), and 8.7% represented images of trains. The researchers concluded that the younger students likely equated engines with car engines — and then related engineers with car mechanics — while the older students were more likely to understand that engineers participate in the process of design.

Methods

Context

This study was conducted over a one year span from 2017-2018 in two different Kentucky public middle schools. Per the National Center for Education Statistics (2017) one school (Treatment), based upon the location within a city with a population of more than 250,000 citizens, was labeled "big city," and the other school (Comparison) was labeled "distant town," as it was distantly located from the, "big city." Additionally, the "distant town," has a population less than 40,000 people (SuburbanStats, 2018). As these labels are not synonymous with the labels of Urban and Rural, many studies concerning Urban schools do not even define what it means to be Urban (Artiles, Rueda, Salazar, & Higareda, 2005; Buckley, Schneider, & Shang, 2004; Stein & Coburn, 2008), and the Rural students in this study do not tend to be more homogeneous than Urban students in this study (Kentucky Performance Rating for Educational Progress, 2014) as McCracken and Barcinas (1991) would expect them to be, the differences between Urban and Rural schools were not focused on in this thesis. However, it is important to note the Comparison school was a Title 1 school (the school had at least 40% of students enrolled from low-income families, and for that reason, it received additional federal funding to help meet the needs of those students), but the Urban school was not (Kentucky Department of Education, 2017).

Both groups (Treatment and Comparison) were taught with NGSS, as these standards are utilized in this region. The Big City middle-school has worked with members of this research group since 2015, when they were recruited to attend and participate in professional development to learn how to teach the chemistry-based engineering design unit implemented to the treatment students in this study (See Tables 2-3 for what the treatment teachers actually implemented from the unit). At the time of this study, the treatment teachers had been teaching this unit for the previous two years. The Comparison school was a new contact for this research group, and they were free to teach whatever they had planned to teach during the same period of instruction in which the treatment teachers implemented their unit (see Tables 4-5) for what they chose to teach. This information was obtained from the weekly lesson plan that detailed what they did in class. It took the Treatment teachers 9 - 11 weeks (Treatment teacher 2 and Treatment teacher 1, respectively) to complete the chemistry-based engineering design lessons. Due to this, the Comparison teachers filled out a detailed weekly lesson plan for roughly the same duration (13 weeks). These lesson plans (see Tables 2-5) were analyzed for engineering practices or engineering disciplinary core ideas (according to the NGSS and the operating definition of engineering in this paper) as well as for language describing engineering; these have been highlighted in bold font (see Tables 2-5).

Table 2: *Treatment Teacher 1 Lesson Plan*
* Denotes lessons taught by student teacher/substitute teacher when Treatment Teacher 1 was on FMLA.

Week	Week of	Lessons for that week (please be as detailed as possible)
1	11/20/17	*21: Demonstrations (Elephant toothpaste, vinegar/baking soda: endothermic, exothermic) Hot/Cold pack observations. Intro to chemistry. 22-24: Fall break
2	11/27/17	*27: How safe are the chemicals in my food? Engage – Ingredient list, Card Sort, and Define Chemical (as scripted) *28: Share definitions, Elaborate – Article jigsaw in differentiated groups. Read individually, same articles join to discuss, go to mixed groups for discussion. *29: Evaluate (as scripted): Resort cards; discuss; Adapt original chemical definition. One other activity: vocabulary definitions with pictures. *30: The teacher is not sure what occurred this day. *1: The teacher is not sure what occurred this day.
3	12/4/17	These 2 weeks are a mystery to the teacher since she had substitute teachers (2 retired science teachers) and her student teacher collegially planned with the 2 7th grade science teachers but didn't write anything down in the class calendar. However, the teacher knows the activities included: -Reading and guided reading sheets from the Science Explorer Chemical Interactions textbook

		- Atoms/Molecules -PHET lab simulations -PowerPoint on Physical and Chemical properties of matter -Periodic Table of elements, and Chemical/Physical properties foldables from Teachers Pay Teachers. -Reactants and Products -Articles of the week
4	12/11/17	See week 12/4/17
5	1/2/18	3: Reviewed expectations and discussed what was covered in the teachers absence. 4: Case of the missing necklace: Mystery powders lab. Students were presented with crime scene evidence samples (mystery powders) that were found on suspects. They use the physical and chemical properties of the powders to identify the mystery powder and link it to the suspect to solve the mystery. 5: Snow day
6	1/8/18	8: Snow day 9: Finish "Case of the Missing Necklace." Review atoms & atomic theory and states of matter. 10: Lesson 2: When does a cookie become a cookie? Describe process of making cookies; card sort in pairs; introduce "physical and chemical"; resort cards; talk about examples 11: Elaborate: Students draw a table for demonstrations. Table includes column for Demo, Before/After macroscopic, Before/after particulate, Chemical/Physical change. Demonstrations in front; students use science notebooks; student volunteers for modeling illustrations on the board. 12: Quiz: Physical/Chemical properties & Physical and Chemical Changes. Scholastic Magazine Article of the week (student choice)
7	1/15/18	15-17: No school for MLK day and Snow 19: Chemical Change Stations Lab: Students rotate through stations where they made observations and identified evidence of chemical change in items such as glow sticks, hot packs, cold packs, alka seltzers, food, yeast/peroxide, milk/vinegar. Find lab below: Labeled A
8	1/22/18	22: Finish stations lab & **Introducing the Project using demonstrations. Discuss questions students have about making hot/cold packs.** 23: "Can I See S'more Changes?" lab: Students make s'mores and 1) observe physical properties of the ingredients, 2) create macroscopic and particulate diagram models before and after heat is applied, 3) identify/describe evidence of physical and chemical changes in each substance. Find Lab Below: Labeled B. 24: Chemical/Physical properties and changes foldable. Article of the week "The Penny Experiment" about chemical changes in copper. (Readworks.com) 25: Lesson 4: "What Happened to the Mass?" Students create a data table that will display the following: mass before, mass after, macroscopic before, macroscopic after, particulate before, particulate after, predict what will happen to the mass, and what actually happened to the mass. The Google Slides presentation for this section includes the quote from Lavoisier and a short video about his life. The teacher does the demos with the students. Students draw model diagrams on the board for discussion and help. 26: What Happened to the Mass? Explore. The teacher introduced students to options A, B, C, & D. Students wrote on a post-it which option they chose for demonstrating the law of conservation of mass. While students watched a TedEd video, the teacher placed the post-its into groups on lab stations. Students performed their experiment and compiled a class data table on the board. After the lab stations were cleaned, the results were discussed (why some systems conserved mass and others did not) and the Law of Conservation of mass. The teacher also talked about open and closed systems with the class.

9	1/29/18	29: PHET Balancing Chemical Equations computer simulation game about balancing chemical equations. 30: Law of Conservation of Mass power point/Google Slides. Fill in the blank notes. Law of Conservation of mass practice sheet assigned for homework. 31: Law of Conservation of Mass Skittles Lab. Lab Found Below Labeled D. Students use Skittles to build molecules and model conservation of mass of reactants and products. 1: Finish Skittles Lab 2: Post Assessments
10	2/5/18	5-6 Test Review; written and on Quizizz. (2 hour delay) **7-9 Engineering Hot/Cold Pack Lab.**
11	2/12/18	12: Biochemistry Pre-Assessment & Draw an Engineer 13-14: Through Course Task "Chemical Spill" 15: Chemistry Assessment

Table 3: *Treatment Teacher 2 Lesson Plan*

Week	Week of	Lessons for that week (please be as detailed as possible)
1	11/20/17	Thermal Energy Unit.
2	11/27/17	What is a Chemical? Lesson
3	12/4/17	Chemistry pre-test, Bill Nye Atoms video and worksheet, AOW – Everyday Compound or Poison.
4	12/11/17	Chemistry notes, Elements on the Periodic Table, Jigsaw activity with articles on Chemicals. Chemical and Physical Properties review .
5	1/2/18	The students were only in session for two days this week due to snow. One day the teacher had to go back over school and classroom expectations and then went over the finals. The next day the teacher started a class discussion over photosynthesis.
6	1/08/18	Just How Small is an Atom? Formation of a New Substance with notes The Penny Experiment
7	1/15/18	QUIZ - 1/19/18 Answer on a sheet of paper in COMPLETE SENTENCES. 1. Give 3 examples of something that indicates a physical change. 2. Give 3 examples of something that indicates a chemical change. 3. Using your S'more lab tell me if the Peep went through a physical change, a chemical change, or both. Give evidence to support your claim. S'more Lab – Physical vs. Chemical changes Macro vs. Micro Observing Chemical Changes Lab
8	1/22/18	Reactants and Products What is a Chemical Chemical Spill Observing Chemical Changes in Matter Lab Changes and Conservation of Matter
9	1/29/18	Where Does the Mass Go? **Thermal Energy Pack Demonstrations** Comparing the Rate of Reactions Lego Molecular Mass

Table 4: *Comparison Teacher 1 Lesson Plan*

Week	Week of	Lesson descriptions
1	11/06/17	Energy Transfers and Transformations: Students began exploring the different forms of energy. The class looked at Potential and Kinetic energy, specifically.

		The class spent this first week exploring Gravitational Potential Energy and Motion. The teacher also used several PHET simulations. This was tied back to much of the work that was finished in an earlier unit. Energy Transfers and Transformations: Students continued to explore different forms of energy and how it was transferred and transformed. Students built rollercoasters out of tubing. The class explored how brakes work and generated thermal energy.
2	11/13/17	Devoted time to Conduction, Convection, and Radiation. The class explored how thermal energy traveled in each circumstance (one day lab for each transfer). **Students also had to create the perfect insulator to reduce the amount of thermal energy being transferred. The class did this by saving an Ice Penguin.** The students used what they knew about Conduction, Convection, and Radiation to complete the task. Last Writing Prompt: House Insulation- Students could work in groups. Completed Study Guide for Test.
3	11/20/17	Students completed a test, reviewed it, and made corrections. Students as a whole still had trouble with the extended response " Roller Coaster Run," so the teacher spent more time on the concept of energy transfers and transformations. The teacher altered the extended response and gave them time to retake. The class then peer reviewed the extended responses, and the teacher accepted the final piece into their writing folder.
4	11/27/17	The class began reviewing Cell Content: organelles that make up a cell. Students were taught definitions by exploring the organelles and making their own definition. The teacher decided to do this because the students had limited understanding of cell Structure and function. The class then explored the parts of a cell, and students created foldables, posters, and worked in groups of four to gather data about cells. The class spent a lot of time on Mitochondria and explored the question "Why do we have to eat?"
5	12/4/17	Students continued on their work with cells. The culminating activity was the "Cell Journey." The teacher's classroom was turned into a giant cell. Organelles were made as large props. Students had to travel into a cell and explore the function. The class spent the remaining part of the week exploring each organelle and finding all we could about it. There was then a quiz over organelles: structure and function.
6	12/11/17	The class reviewed concepts that were covered all year: chemical reactions, energy transfers and transformations, and cells. Students then took their semester final before winter break.
7	1/2/18	The class began exploring photosynthesis by investigating plants. The class classified photosynthesis as a chemical reaction based on their observations. The class then began exploring the formula for Photosynthesis. The teacher noticed students were struggling with the formula.
8	1/8/18	The teacher spent time reviewing elements, molecules, and compounds with the class. Students had trouble with these concepts, so the teacher purchased Play-Doh and had his students spend time modeling different elements, molecules, and compounds. The class then made models for the Photosynthesis Formula and combined them to form sugars and Oxygen gas. The class spent several days on this, and students took notes in journals.
9	1/15/18	The class used Play-doh to model the glucose molecules used in cellular respiration. The big question was " Why do we eat?" Students generated questions and explored the concept. The question do all cells have the same number of mitochondria? was also asked The class explored these questions using simulations and looked at slides of different cells.
10	1/22/18	Photosynthesis Versus Cellular Respiration. Students created a pamphlet explaining both processes. Test over Photosynthesis and Cellular Respiration.
11	1/29/18	Begin body systems unit:

		Exploring Body System
12	2/5/18	Body System
13	2/12/18	Body Systems

Table 5: *Comparison Teacher 2 Lesson Plan*

Week	Week of	Lessons for that week (please be as detailed as possible)
1	11/06/17	The class finished up with energy transformations and with this, the students had to **design and model a Rube Goldberg Machine.** The class used this machine to guide their discussion about energy transformations. The students had a day of notes and then they had a day of activities to work closely with energy transformations. In the activities, the students had to match flash cards with the correct energy transformation. At the end of the week, the students had a quiz and they had an article that they had to read and answer questions about that went along with energy.
2	11/13/17	This week the class started learning about thermal energy. The class had a day where the students learned what thermal energy is as well as the different types of thermal energy. **The students took a day to design an igloo that would keep an ice penguin from melted from heat lamps. The next they constructed the igloo and tested it and then the next day they redesigned it.**
3	11/20/17	This was a test week for the students. Therefore, the class reviewed on that Monday and took the test on that Tuesday. This was Thanksgiving week so there were only had 2 days of school.
4	11/27/17	After Thanksgiving break the class took a day to go back over classroom and school expectations and to go over the test the students had taken. The class then started a unit on cells. The students first learned about all the different types of organelles and made flash cards to help remember them. The class then spent a day on plant cells and constructed a plant cell in their interactive notebooks. The teacher ended the week with a quiz and an article over plant cells.
5	12/4/17	This week we learned about animal cells. We compared and contrasted the animal and plant cell. They were able to create an animal cell in their interactive notebooks. The students then learned about bacterial cells and how they are alike and different from plant and animal cells. The students then constructed a bacterial cell in their interactive notebooks. The students ended the week with a quiz over the cells and an article over cells.
6	12/11/17	This week was finals week, which took place on Thursday and Friday. The students received a study guide and were able to work on it together for one day. The next day the teacher went over the study guide in detail and gave them any information that she thought they would not have thought of. The students reviewed with a review game the next day to prepare them for the final. Thursday and Friday were finals, so the teacher did not see all of her regular classes.
7	1/2/18	The students were only in session for two days this week due to snow. One day the class had to go back over school and classroom expectations and then over the finals. The next day the teacher started a class discussion over photosynthesis.
8	1/8/18	The classes were in session for three days due to snow. This week the class dived into photosynthesis by looking at the formula and what it actually meant. The students were able to create the molecules that make up photosynthesis and see how the reactants made up the products. The students then continued on to learn about cellular respiration and how it relates to photosynthesis. The students made a graphic organizer in their interactive notebooks where they were able to exactly see how photosynthesis and cellular respiration was alike and different.
9	1/15/18	There was only one day of school this week due to a holiday and snow. On this one day, the students participated in an interactive lab on the computers. During this lab, the students were able to prove that photosynthesis takes place in plants by counting the number of oxygen bubbles produced by a plant when placed

		under a light. The students also learned how the distance of a light source effects the plant as well.
10	1/22/18	This week the students continued their exploration with the carbon cycle. The students learned how the carbon cycle, photosynthesis, and cellular respiration are related. The next day the students were modeled as carbon atoms and they rolled dice and traveled around the room as carbon atoms. At the end of the activity, the students were able to tell me just how much time carbon spends at one particular stage of the carbon cycle. The students continued their learning adventure with learning how photosynthesis effects the ecosystem. The students took notes one day and then the next they modeled in their notebooks how energy travels in an ecosystem. They ended the week with a quiz and an article over the carbon cycle.
11	1/29/18	The class ended the photosynthesis unit this week. The class started the week by doing an interactive lab on the computers testing how different colors of light effect the growth of plants. By the end of the week the students were able to tell me what colors of light increased the rate of photosynthesis and which colors decreased the rate. The students were given a study guide and the class went over it in detail together. The students were able to play a review game before the day before the test. The students took the test on that Thursday. That Friday the students worked on vocabulary for the next unit since the unit is very vocabulary intensive.
12	2/5/18	Classes were only in session l for two days due to snow and illness, so the students researched 11 different body systems and created a theme park using 5 of those body systems. They had to draw the theme park and create names for the rides that they chose to create using something associated with that body system.
13	2/12/18	On Monday, the class had a visit from the librarian to teach the kids how to make a brochure because the Language Arts teacher, the librarian, and the science teacher were collaborating on a project for all the advanced kids in the seventh grade. On Tuesday, the students started learning about the digestive system and the organs and components associated with it. On Wednesday, the students constructed the digestive system in their interactive notebooks. On Thursday, the students learned about the respiratory system and all the organs and components with it. On Friday, the students were in the library working on their research and brochure for the project.

According to the teacher templates (Tables 2-5), the Comparison students received the same amount of, if not more, engineering design during the 9-13 weeks of instruction as the Treatment students. Specifically, Treatment teacher 2 only had time to discuss the engineering design activity with her class and show the relevant demonstrations (this took only one class period), but she did not have time to have the students participate in the actual engineering design activity of designing a hot/cold pack to keep them comfortable because that would take an extra three days. Even when all of the chemistry-based engineering design components were implemented by Treatment teacher 1, those students still only received a maximum of four, 50 minute science periods that focused on engineering design. When this is compared to the instruction the Comparison group received – 3 days of engineering design based around "saving" an ice penguin (Comparison teacher 1 and Comparison teacher 2) – plus a class period of designing and modeling a Rube Goldberg machine (Comparison teacher 2's students only), it appears that at least half of the Treatment group (Treatment teacher 1's students) received less engineering design than did the Comparison group. To gain more insight on the teacher's understanding of engineering, each teacher was interviewed prior to instruction using a semi-structured interview protocol.

Design

This qualitative quasi-experimental study investigated how middle level science students understand engineering before and after instruction. To begin, all the participating students from four teachers (2 Comparison and 2 Treatment) filled out the Views of Nature of Engineering (VNOE; Deniz et al., 2017) survey and the Draw an Engineer Test (DAET; Knight & Cunningham, 2004). Additionally, four students (2 boys and 2 girls) from each teacher were randomly selected in Microsoft Excel, and these students underwent semi-structured student interviews (see Table 6; Driessen et al., 2018).

Instruction began after the aforementioned data was collected. Treatment teachers taught a specific chemistry curriculum, Chemical Reactions Engineered to Address Thermal Energy Situations (CREATES), which was designed around the Next Generation Science Standards with engineering practices entwined throughout as well as an engineering design component; note these teachers had been previously trained to teach this curriculum and had taught it for the previous two years (Cole, 2017; Wilhelm, Wilhelm, & Cole, 2019). Comparison teachers had no instructional constraints and were therefore free to teach anything.

After instruction, the previously interviewed students were interviewed again, and all of the participating students completed the DAET and VNOE again. The interviews (both pre and post) were transcribed and summarized into categories and themes. The data collected was used to answer the research questions (see Table 6).

Table 6. Research Questions and Methods

Question		Data Collection and Instrumentation	Coding Method
1.	How do middle level science students view engineers and engineering before and after instruction?	Views of the Nature of Engineering (VNOE; Deniz et al., 2017) survey (all students), the Draw an Engineer Test (DAET; Knight & Cunningham, 2004; all students), and student interviews (2 boys and 2 girls from each of the four teachers' classes)	VNOE responses were categorized. A checklist was used to group student DAET responses into certain categories (Fralick, 2009). Student interviews were analyzed for recurring and dominant answers (specific words or phrases).
2.	Do middle level science students who experienced a chemistry-based engineering design unit have a different understanding of engineers and engineering than the Comparison students who experienced lesson plans as usual?	Same as for research Question 1.	Same as for research Question 1
3.	How do teacher understandings of engineering and engineers compare to their students?	Teachers' understanding of engineers and engineering as revealed by the teacher interviews were compared to the students' understanding of engineers and engineering as elucidated by the VNOEs, DAETs, and student interviews.	Teacher interviews were analyzed for recurring and dominant answers (specific words or phrases).

Participants

Research subjects were from two middle schools in Kentucky, one Big City(Treatment) and one Rural (Comparison). Two seventh-grade science teachers from each school volunteered to participate in this study. At the time this research was being conducted, Treatment teacher 1 was Female and had 16 years of teaching experience and no prior careers, Treatment teacher 2 was Female and had 17 years of teaching experience and no prior careers, Comparison Teacher 1 was Male had 11 years of experience and no prior careers, and Comparison Teacher 2 was Female and had 3 years of experience and was previously a genetic engineer. Each of those four teachers sent their students home with consent forms. The students who brought back a completed form with positive consent and assent became participants in the research as well. These teachers and students were divided into two groups: (1) Comparison and (2) Treatment. The Comparison school was located in Rural Kentucky while the Treatment school was located in a "Big City" in Kentucky. The Treatment school was one of 12 middle schools in its district, while the Comparison school was one of two middle schools in its district. Of note, the schools in this study were chosen for convenience as the researchers had a previous relationship with the Treatment school, and the Comparison school was located near one of the researchers. These schools were comparable as far as race/ethnicity and standardized science test scores However, the Treatment students outperformed the Comparison students on the 2016-2017 K-PREP mathematics test (Kentucky Department of Education, 2017). Another difference among the schools concerns the fact the Comparison school was a Title 1 school (at least 40% of the students enrolled were from low-income families, so the school received additional federal funding to help meet the needs of those students), but the Treatment school was not (Kentucky Department of Education, 2017). Please see Driessen et al. (2018) for further participant details.

Results

This section presents the research findings from this experiment in the following order: (1) highlighted and summarized teacher interview responses prior to teaching the lessons elucidated in this research; (2) student interview responses both before and after instruction; (3) pre/post student Views of Nature of Engineering (VNOE) survey responses; and (4) pre/post student Draw an Engineer Test results.

Teacher Interviews

Table 7: *Teacher Interview Excerpts That Elicit Their Understanding of Engineering*

Comparison Teacher 1	Comparison Teacher 2	Treatment Teacher 1	Treatment Teacher 2
So, we are going to be making uh penguin ice cubes and then the kids will have to develop a way - we'll give them a bunch of materials and we'll - we want them to understand the difference between a conductor and an insulator, and so, from that we need them to save the penguins. So, we'll be putting these under heat lamps and then we'll give them some time to see who can come up with a device to **solve that particular problem**. Keep it colder for the longest amount of time.	My first profession was not teaching it was a genetic engineer. Where I took chromosomes to see where the problem is. The **engineers solve the problems.** I would see what is in the gene for the chromosomes. I have a student whose father is an electrician at Toyota, he told me there are sometimes where something happens, and he has to **fix it and make everything run again**. I think teachers are engineers because they have to **solve so many problems** to solve.	Things that have been engineered: "Oh yeah **bridges** and **buildings** and schools and this printer."	I was explaining it to the kids yesterday is I said architects, because we are doing that house project, so this is the easiest way to answer it, it might be a cop out, but **the architects design it** and the **engineers are who are in charge of all of the products and putting it together**.

Engineering you basically have a **problem you try to solve it**. If it doesn't succeed the first time you look back at what you did wrong or what happened and then you go back, and you do it until you can solve that problem. That's engineering to me.	I love engineering; I'll make my students **build** as much as I can in a unit. I have done all kinds of projects like the roller coaster, igloos, they **design and redesign** things all the time. We talk about why we did the redesign. I try to have them **build** something at the beginning or the end, so they can see what they have learned and then applied it at the end.	I think of engineering as more of the **planning building design.** Engineering you basically have a **problem you try to solve it**. If it doesn't succeed the first time you look back at what you did wrong or what happened and then you go back, and you do it until you can solve that problem. That's engineering to me.	I feel like engineers are kind of **problem-solvers**, um, so, if you look at it in broader spectrum, that way, then we can all kind of be engineers.

Several engineering themes were revealed by the teacher interviews. These include: engineers solve problems (Comparison teacher 1, Comparison teacher 2, and Treatment Teacher 2), engineers design (Comparison teacher 2 and Treatment teacher 1), engineers redesign (Comparison teacher 1 and Comparison 2), engineers build (Comparison teacher 2), engineers fix things (Comparison teacher 2), and engineers "are in charge of all of the products and putting it together.

Student Interviews

Four students from each of the four teachers were selected randomly in Excel by the researcher. Those students were then interviewed before and after instruction for a total of 16 interviewed students (8 boys and 8 girls total). These interviews were transcribed and examined. The answers to one question was highlighted: What is Engineering/What do you know about Engineering? Interview excerpts were then taken from the transcripts for each student, for both the pre and post-interviews, and a table was constructed. See Table 8 for interview excerpts answering the highlighted question.

Table 8: *Treatment Versus Comparison Student Interview Answers to the Question: What is Engineering (E)?/What do you know about E?*

	Treatment Student Group		Comparison Student Group	
Student	Pre-Instruction	Post-Instruction	Pre-Instruction	Post-Instruction
Girl 1	Umm, you **build** things.	Um, they **design** and **build** things.	**I don't know**, not really a whole lot, I can't think of any specific machines…	**I don't really know** um it's like **mechanical** stuff. Like, like has something to do with **cars.**
Girl 2	A **design process** where you have an idea and you make a **blueprint** and then you do a **model**…	Uhm **everything around us is engineered** and I think everybody is an engineer.	Don't they work with like **technology**?	**Ew. Nothing** really.
Girl 3	You **build** things.	Where someone **builds** something that works. Like **technology.**	**I don't really know** a lot.	engineering is like um someone helps…like **make something** or kind of **help build** it.
Girl 4	I think of like **building**, like, something, so, like, when you build something, you'll need, like, **blueprints, materials**, and stuff…	[No data for this student]	**I don't really know** anything about E. The only time I've heard about E is about **cars**. Like car engineers.	um I know that it has to do with **math and science** yeah.
Boy 1	So, my sister's husband is an environmental engineer …what he does is he **tests the water, test the air for pollution**…	…so there's **chemical engineers** that involve chemicals, **civic engineers, uh, environmental engineers, electricity, electrical engineers, plumbers are like kind of engineers** and I think that is it.	I've not heard of it a lot but…, **I don't know**, not really. I always think about **mechanics** when I hear that for some reason.	Uh, well, engineering is like the **construction**, it's like the **background of science**, and it's like constructing, uh, it's like the **physical construction of science** rather than the like experimental.
Boy 2	Engineering is like the process where you use to **make** things.	Engineering is like **building** and **solving problems**, things like that.	Uh. I know it's like **building**. It's like **mechanic** type thing. **I don't know** if I'm correct.	It's something that you would like **fix like cars** or something like **put tires together** or something.
Boy 3	You **make** something for any purpose really, but, like, it's you're **building** something and **designing** something…	It mostly is **designing** something and **building** something, usually.	**Nothing**.	**Not much.**
Boy 4	Like **building buildings** and **bridges** and stuff, and just basically any **landscaping** stuff.	Engineering's, um, a lot of **math and science** and you...**design ideas**… robots, buildings, bridges, structures...	**All I know is**… [The student hesitated and then did not respond]	Um. Not a lot. Like I know I know the concept of it but it kinda just gets thrown around, but **I don't really understand it that much**.

Table 8 shows there are obvious differences between the Treatment and Comparison student responses to the questions: What is Engineering (E)?/What do you know about E? Specifically, pre-instruction, of 8 Treatment students, 5 noted engineers "build things;" two reported engineers use blueprints; and one noted engineers use models, use the design process, test for pollution in the air and water, make things, landscape, and design, in general. Of the eight pre-instruction Comparison students, eight either mentioned they didn't know much or anything about engineering or they expressed doubt in their answers, two noted engineers have something to do with mechanics, and one reported engineers do "everything," build, use technology, or are car engineers. Post-instruction, while only seven of the original eight Treatment students responded, three stated engineers design and build and one student mentioned one of the following: engineers use technology, test water, use math and science, or solve problems. One student did not respond to this question, one stated everything is engineering and everyone is an engineer, and one listed types of engineers including chemical, civic, and environmental engineers. After instruction, of the same 8 Comparison students, four stated they did not know what engineering is, two determined engineers use science, one reported engineering is mechanical, one stated engineers help make and build, one decided engineers do not experiment, one stated engineers fix cars and put tires together, and one noted engineers use math. This shows the Treatment group never responded that they didn't know anything or were unsure about engineering, both prior to and after instruction, while 100% of the pre-instruction and 50% of the post-instruction Comparison students did. Secondly, one Treatment student mentioned design and the design process pre-instruction, and three Treatment students mentioned design post-

Treatment, while none of the Comparison students mentioned design or the design process in their interviews pre- or post-instruction. Thirdly, two of the Comparison students mentioned mechanics and one mentioned car engineers prior to instruction, and, post-instruction, one Comparison student reported cars, one noted construction, and another student stated engineers fix cars and put tires together. The Treatment students did not mention any mechanics, car engineers, construction, or fixing cars and putting tires together.

View of Nature of Engineering (VNOEs)

The VNOE survey was given to all consenting students and was administered within students' regularly scheduled science class. Treatment students took the survey using computers, while Comparison students took the survey on paper due to technology limitations within the school.

After the Views of Nature of Engineering (VNOE) were completed and submitted, they were sorted into consenting and non-consenting student responses. Of the consenting students, there were 121 pre-instruction Treatment, 109 post-instruction Treatment, 97 pre-instruction Comparison, and 83 post-instruction Comparison student responses to the VNOEs. The following four VNOE questions were highlighted: (1) *What is Engineering/What do Engineers do?,* (2) *How is engineering different from the other subjects you are learning?*, (3) *Have you ever heard of the engineering design process?,* and (4) *Have you ever thought about being an engineer?* After these were collected and reviewed, the answers were coded and categorized by two of the researchers. The researchers then compared categories and results. Certain categories (see

Figures 1-4) were selected. After that, three researchers separately coded all student answers into the previously selected categories. These results were then compared. Interrater reliability was first established between 75 – 90% during the first round of coding, but after discussion interrater reliability was 99% for all question responses.

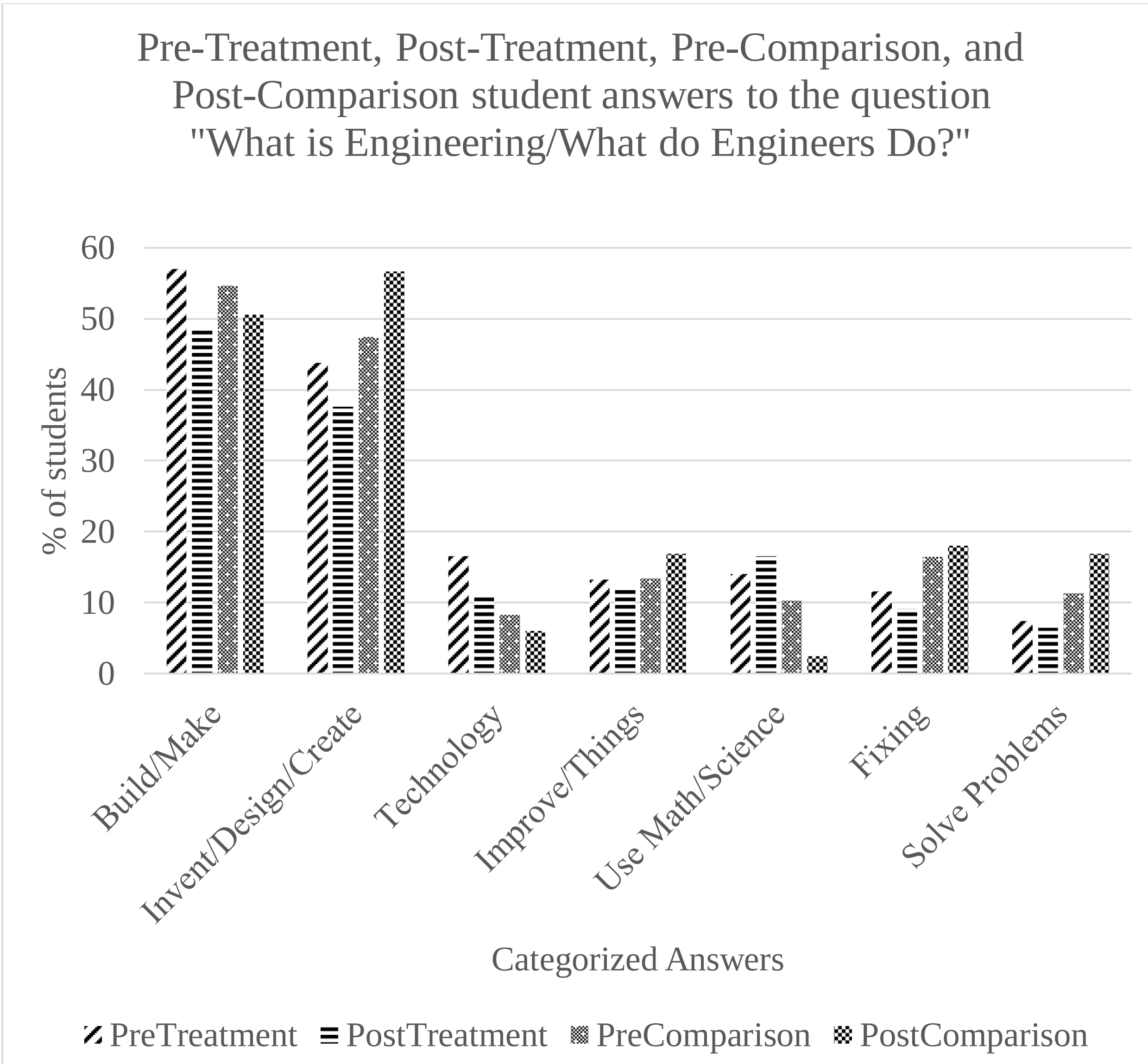

Figure 1: A comparison of the percentage of Treatment and Comparison student categorized Pre- and Post-instruction answers to the Views of Nature of Engineering Question: What is engineering/What do engineers do?

The most popular pre-instruction answer to the VNOE question *What is engineering/What do engineers do?*, for both Treatment and Comparison students, was categorized as build/make (57.02% of Treatment and 54.64% of Comparison students; see Figure 1). Post-instruction, 48.62% of Treatment and 50.6% of Comparison students responded with build/make. The second most popular pre-instruction categorized answer was invent/design/create (43.80% of Treatment students and 47.42% of Comparison students). Post-instruction, this categorized answer decreased for Treatment students (37.61%) but increased for Comparison students (56.63%). “Technology,” “improve things,” “use math/science,” “fixing,” and “solve problems” were the lesser mentioned responses by Treatment and Comparison students both prior to and after instruction.

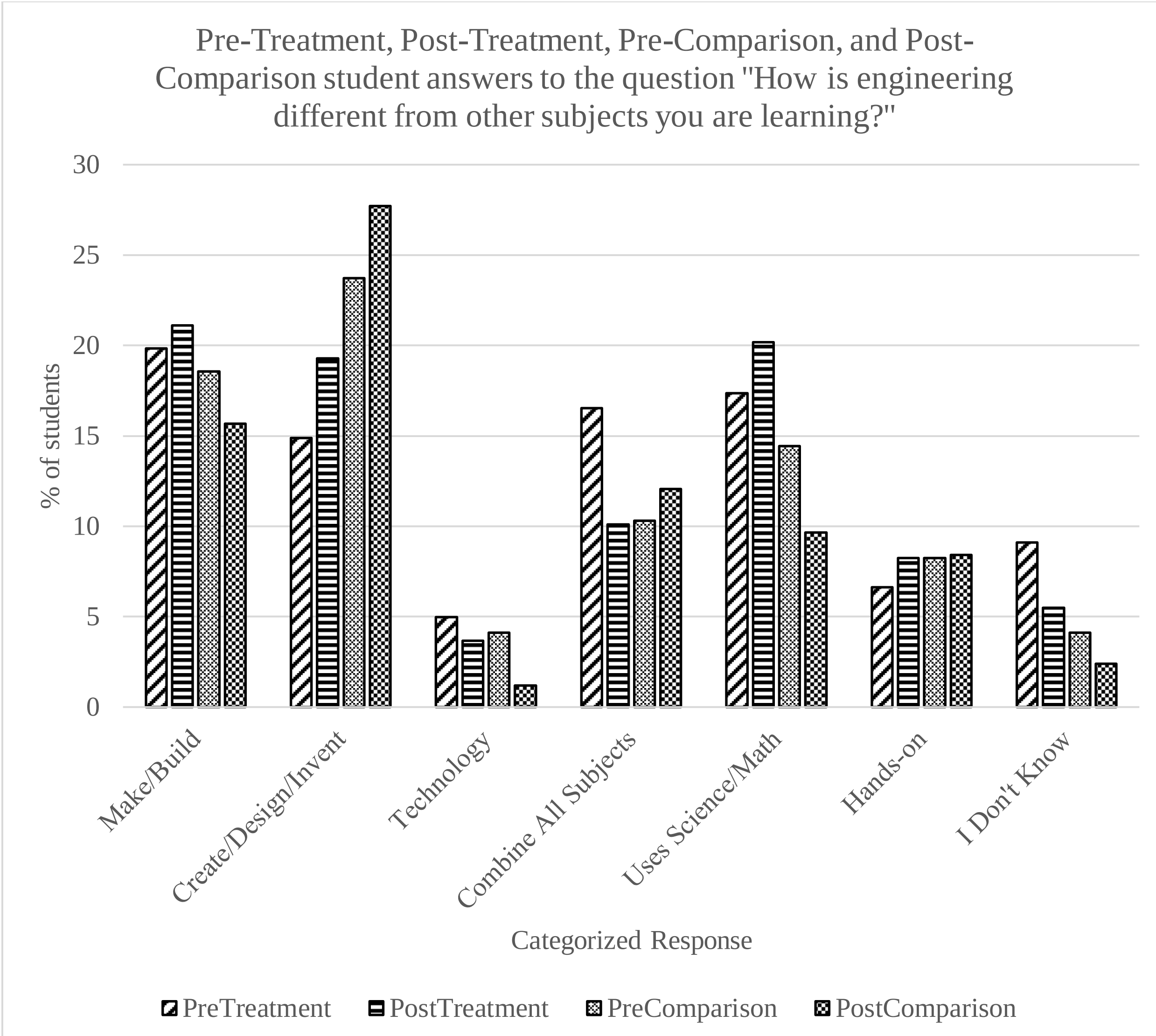

Figure 2: A comparison of the percentage of Treatment and Comparison student categorized Pre- and Post-instruction answers to the Views of Nature of Engineering Question: How is engineering different from other subjects you are learning?

For Treatment students, the most popular pre-instruction answer to the VNOE question *How is engineering different from other subjects you are learning?* was categorized as make/build (19.83%) whereas it was create/design/invent for Comparison students (23.71%); only 18.56% of Comparison students answered make/build (the second most popular answer for Comparison students) while only 14.88% of Treatment students answered create/design/invent (the third most popular category for Treatment students; see Figure 2). Post-instruction, the percentage of Treatment student answers categorized as build/make increased to 21.10% while the percentage of Comparison student answers for the same category decreased to 15.66%. The create/design/invent answers increased from pre- to post-instruction for both the Comparison and Treatment students (27.71% and 19.27%, respectively). The second most answered category for Treatment students, pre-instruction, was uses science and math (17.36%), while this was 14.43% for Comparison students (the third most common category for Comparison students). Post-instruction, the percentage of Treatment student answers categorized into uses science and math increased to 20.18% while it decreased for the Comparison students to 9.64%. The categorized answer “combine all subjects” was reported by 16.53% of Treatment and 10.31% of Comparison students prior to instruction and by 10.09% of Treatment and 12.05% of Comparison students after instruction. The categories “I don’t know,” “hands-on,” and “technology” were mentioned the least by both groups.

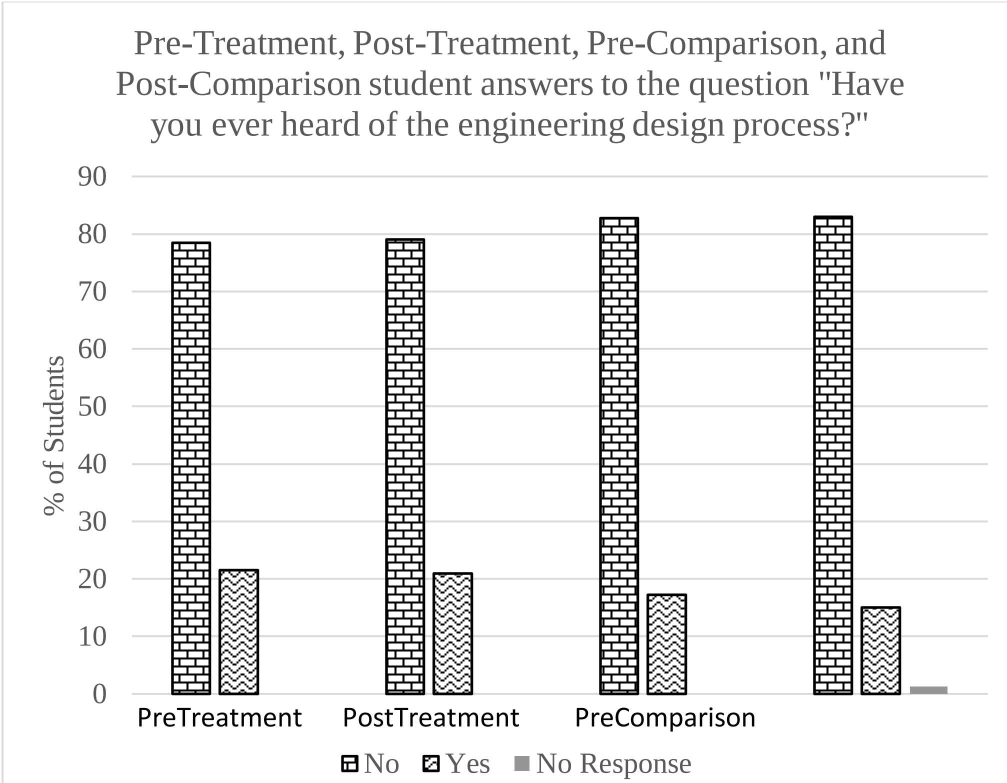

Figure 3: A comparison of the percentage of Treatment and Comparison student categorized Pre- and Post-instruction answers to the Views of Nature of Engineering Question: Have you ever heard of the engineering design process?

Student pre-instruction responses to the VNOE question *Have you ever heard of the engineering design process?*, for both Treatment and Comparison, were overwhelmingly categorized as “no” (78.5% and 82.8%, respectively). Post-instruction, the answer “no” was still favored, and it actually increased for both Treatment and Comparison groups (79.00% and 83.00%, respectively; see Figure 3). The percentage of Treatment and Comparison students who answered “yes” was 21.5% and 17.2% pre-instruction and 21.00% and 15.00% post-instruction.

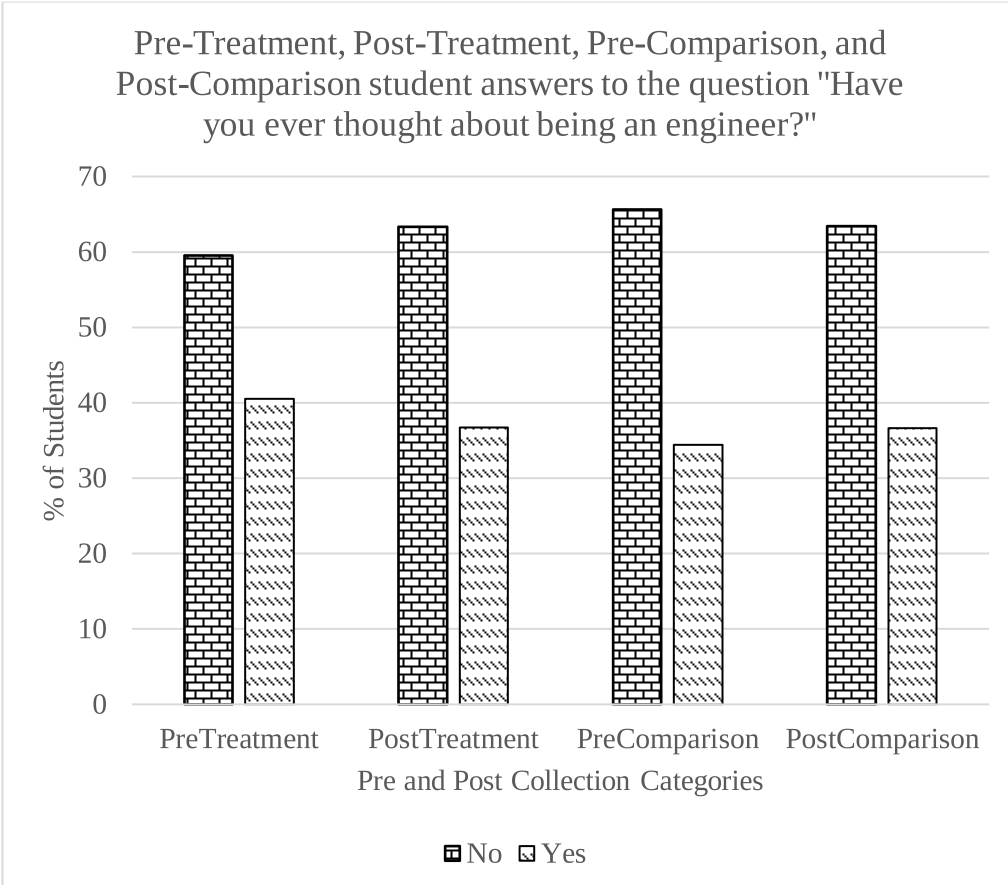

Figure 4: A comparison of the percentage of Treatment and Comparison student categorized Pre- and Post-instruction answers to the Views of Nature of Engineering Question: Have you ever thought about being an engineer?

From pre- to post-instruction, the percentage of Treatment students who answered "no" to the question *Have you ever thought about being an engineer?* increased from 59.5% to 63.3%. However, for the Comparison students, this percentage decreased from pre- (65.6%) to post-instruction (63.4%; see Figure 4). The percentage of Treatment students who answered "yes" to the same question decreased from pre-instruction (40.5%) to post-instruction (36.7%), while the percentage of Comparison students who answered "yes" increased from 34.4% to 36.6%.

Draw an Engineer Tests (DAETs)

The DAET consisted of a piece of paper printed with the prompt: "draw a picture of an engineer," a large empty square box in which to draw an engineer, and a few lines following the prompt: explain the drawing. It is important to note a difference between the DAET ("draw a picture of an engineer") used in this research and the DAET ("draw a picture of an engineer at work") developed by Knight and Cunningham (2004). After the DAETs were completed (see Figure 5 for examples) by both the Comparison and Treatment students pre- and post-instruction, they were sorted into consenting and non-consenting student piles. The consenting student DAETs were analyzed and coded using the Fralick, Kearn, Thompson, and Lyons (2009) evaluative tool with an interrater reliability of 97%. This data was then compiled into a graph (see Figure 6) to show the top four inferred actions the students drew their engineers performing.

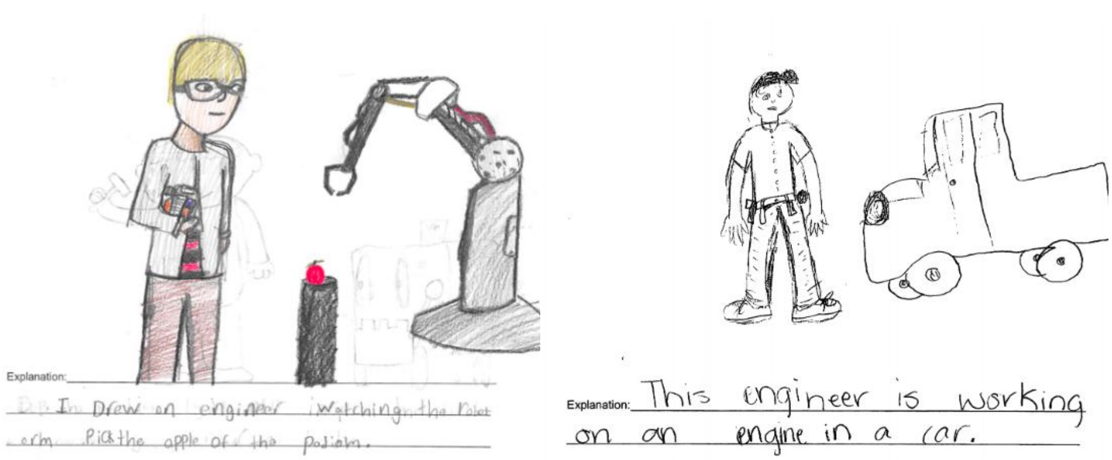

Figure 5: Completed student Draw an Engineer Tests (DAETs). The drawing on the left is captioned: "I drew an engineer watching the robot arm pick the apple off the podium." The drawing on the right is captioned: "This engineer is working on an engine in a car."

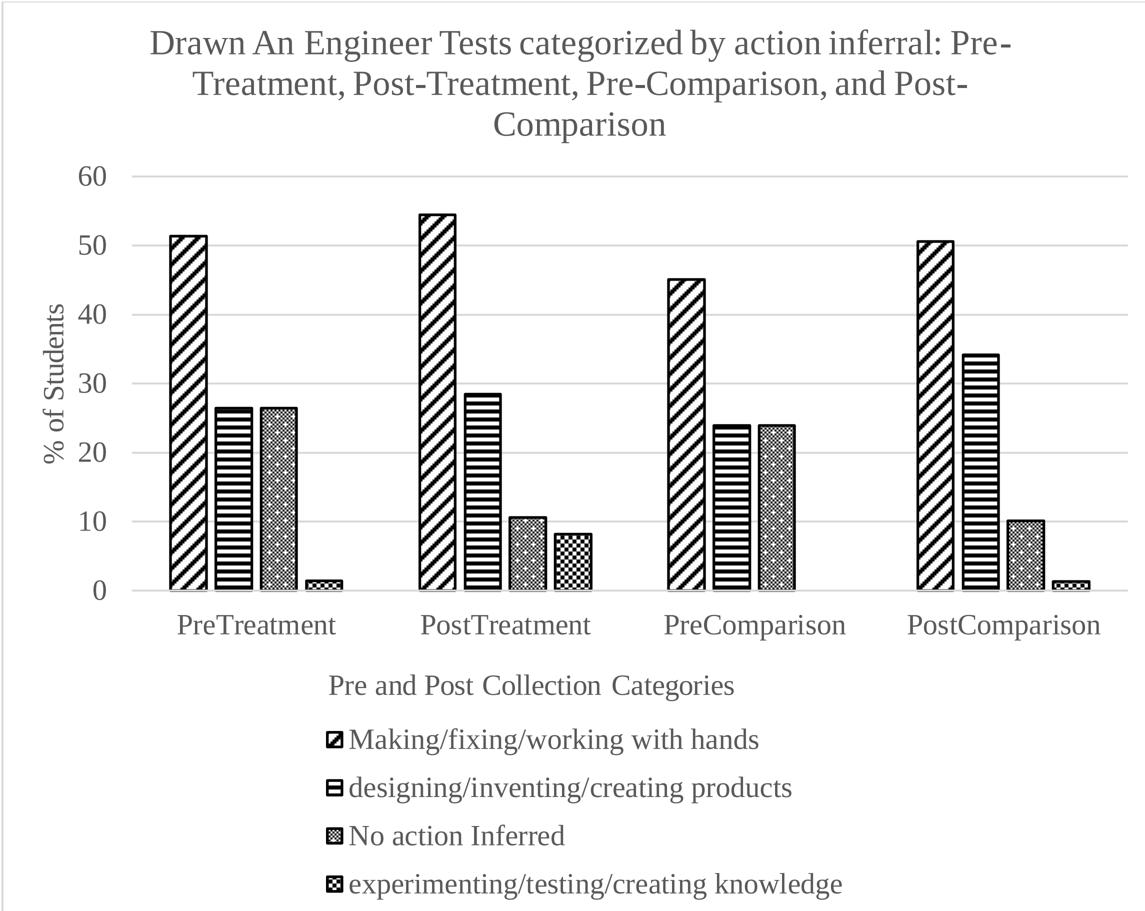

Figure 6: A comparison of the percentage of drawn engineers performing categorical actions for Treatment and Comparison students Pre- and Post-instruction.

Pre-instruction, the most common drawn engineer action for both Treatment and Comparison students was making/fixing/working with hands (51.39% and 45.07%, respectively). Post-instruction, making/fixing/working with hands was still the most common action Treatment and Comparison students drew their engineers performing, albeit slightly higher than pre-instruction (54.47% and 50.63%, respectively). The second most common pre-instruction action for the student drawn engineers was designing/inventing/creating products (26.39% of Treatment and 23.94% of Comparison students). Post-instruction, the percentage of Treatment and Comparison students that drew their engineers designing/inventing/creating products increased from pre-instruction to 28.46% and 34.18%, respectively. The third most common categorical inferred action from the drawn engineers was "no action inferred"; The percentage of students, from both the Treatment and Comparison groups, that drew their engineers doing nothing inferable decreased from pre-instruction (26.39% and 23.94%, respectively) to post-instruction (10.57% and 10.13%, respectively). Finally, the least represented category in Figure 6 was experimenting/testing/creating knowledge, however, the percentage of Treatment and Comparison student answers coded into this category increased from pre-instruction (1.39% and 0%, respectively) to post-instruction (8.13% and 1.27%, respectively; see Figure 6).

Discussion

Differences Between Pre- and Post-Instruction Understanding

In answering the first research question, *how do middle level science students view engineers and engineering before and after instruction?*, all of the data collection methods (i.e. student interviews, VNOEs, and DAETs) were compared from pre to post instruction for both of the groups. The results demonstrated that from pre- to post-instruction (1) a smaller percentage of students, from both groups, reported having heard of the engineering design process (VNOE), (2) a smaller percentage of Treatment and Comparison students noted they have thought about being an engineer on the VNOE, (3) fewer students, from both groups, drew engineers with no action inferred (DAET), (4) all of the interviewed students became less likely to say "I don't know" when asked What is engineering/What does an engineer do? and (5) students, from both groups, were less likely to answer "I don't know" to the VNOE question, "How is engineering different from other subjects you are learning?" Each of these findings will be discussed in this section.

The first noted finding, the percentage of students, from both groups, that reported having heard of the engineering design process decreased from pre- to post-instruction is surprising. This means that even after participating in three days of an engineering design activity, Save the Penguins (Schnittka, Bell, & Richards, 2010) – with the emphasis, at least in the curriculum, placed on the engineering design, the Comparison group had somehow heard of the engineering design process less than before. In the same vein, even after the Treatment group experienced 4 days (Treatment teacher 1) or 1 day (Treatment teacher 2) of engineering design (CREATES; Wilhelm, Wilhelm, & Cole, 2019), a smaller percentage of students had noted having heard of the engineering design process. This was surprising but could be due to an emphasis being placed on phrasing other than the exact words "engineering design process." For example, Save the Penguins states the design challenge is "to **build** a dwelling for a penguin-shaped ice cube in order to keep the penguin from melting" (Schnittka, Bell, & Richards, 2010, p. 87). Similarly, CREATES states the engineering design project is, "**building** a hot or cold pack" (Wilhelm, Wilhelm, & Cole, 2019, p. 138). This could explain the increase, albeit it small, in the percentage of drawn engineers, from both groups, with inferred actions of making/fixing/working with hands. However, this is not supported by the post-VNOE answers to the questions "What is engineering/What does an engineer do?" or "How is engineering different than other subjects you are learning?" since the percentage of student answers categorized as make/build decreased, for both groups, from pre- to post-instruction, while it increased for the category of invent/design/create. This ultimately demonstrated an increased understanding of engineering, as defined in this paper (i.e. *Engineering is the* ***design*** *and improvement of ideas, systems, and products through the use of prior knowledge, mathematics, science, and technology; An engineer problem-solves and* ***innovates*** *to advance the community around them and fulfill a human need).* With this in mind, perhaps the reason students from both groups noted they had heard of the engineering design process less post-instruction than on the pre-instruction VNOE is because they haven't recognized the engineering design process as all of the motions they were going through during the design challenges either in CREATES or Save the Penguins.

The second noted finding, a smaller percentage of Treatment and Comparison students noted they have thought about being an engineer on the post-VNOE than on the pre-VNOE, is difficult to explain considering once a student has thought about being an engineer, it would be impossible to "unthink" about it, which is basically what the students' results are demonstrating occurred. Aside from the fact that it is an illogical finding, at least half of it (the Comparison group's decrease in having thought about being an engineer) is not supported by the literature. Specifically, Schnittka, Bell, and Richards (2009) noted increased student attitudes toward engineering after implementation of the STP curriculum over 7 class periods. Perhaps the discrepancy lies in the fidelity with which the curriculum was taught. This could include the time period in which it was taught (i.e. 4 class periods for the Comparison group in this research versus the 7 class periods for the Schnittka, Bell, and Richards (2009) study) or even the language that was used by the teachers to describe the tasks (e.g. make/build a dwelling rather than use the engineering process to design a dwelling). This finding may also be due to interpretation of the question. Maybe the students interpreted the question to mean "would you ever be an engineer." As students went through the engineering design process, as both groups teachers stated they did, perhaps they realized they would not want to be an engineer. Either way, this finding suggests lowered interest in wanting to be an engineer.

The third finding – fewer students, from both groups, drew engineers with no action inferred on the post-DAET – could suggest two opposing theories. The first theory is that since the DAET prompt simply stated, "Draw an engineer," – and an engineer can look like anyone and doesn't have to be doing anything – this simply occurred on the pre-DAET and occurred less on the post-DAET by chance. The other theory is that this was not by chance, but rather that this suggests a higher percentage of students now have an idea of what actions engineers perform, which is why fewer students drew engineers with no inferred action. This finding does not align with Knight and Cunningham's (2004) findings since 0% of their DAETs were classified as not having an inferred action, however, the DAETs were categorized differently in that tools, products, and actions were used to categorize the drawings in Knight and Cunningham's (2004) research rather than only using actions and written explanations to deduce what the engineer is doing as was done in this research. However, even with that in mind, it is difficult to believe that of the 253 student drawings obtained by Knight and Cunningham (2004) all of them expressed either building/fixing, design, products of mechanical engineering, products of civil engineering, or images of trains and that none of the students just drew a person that was difficult to classify into any category. This is especially difficult to believe given the historically low engineering understanding expressed by students (Jordan & Snyder, 2013).

The final findings — all of the interviewed students were less likely to say "I don't know" when asked the VNOE questions "What is engineering/What does an engineer do?" and "How is engineering different from other subjects you are learning?" and are more likely to give an answer in line with the definition of engineering used in this paper — are indicative of increased engineering understanding. Other studies have shown engineering design intervention engages students in sciences (Huang, Brizuela, and Wong, 2008) or improves attitudes toward engineering (Schnittka, Bell, & Richards, 2009), however, studies measuring understanding of engineers and engineering after receiving a science-based engineering design curriculum are rare. This calls for more studies of this kind in the future to make sure this finding is not an aberration.

Treatment versus Comparison Student Understanding

To answer the second research question, *do middle level science students who experienced a chemistry-based engineering design unit have a different understanding of engineers and engineering than the Comparison students who experienced lesson plans as usual?,* it is important to look at all of the data to paint a holistic picture of each student groups' understanding after receipt of instruction. This includes looking at the VNOE responses, the DAET responses and the student interview responses both pre- and post-instruction. Each of these are addressed.

The DAET demonstrated a similar understanding of engineering for the Treatment and Comparison students in that similar percentages of the same drawn engineer actions were inferred. When looking at slight differences, however, the Comparison student group drew a higher percentage of engineers designing/inventing/creating products than did the Treatment students on the post DAETs, even though they originally drew fewer engineers with this inferred action category on the pre-DAETs. This could be due to the focus that Save the Penguins, the engineer-design curriculum implemented to the Comparison students over four days, placed on designing, inventing, and creating "energy-efficient dwellings" for ice penguins (Schnittka, Bell, & Richards, 2010, p. 82) Additionally, drawn engineers with inferred actions categorized as experimenting, testing, and creating knowledge increased for both the Treatment and Comparison groups, however the percentage of Treatment group drawings categorized in this way was more than twice that of the Comparison group. This difference could be due to the focus the chemistry-based engineering design unit, CREATES, that the Treatment group received, places on experimenting and testing over 9-11 weeks of implementation (Wilhelm, Wilhelm, Cole, 2019), while the Save the Penguins curriculum only took four days.

The VNOE questions elicited similar results among the two student groups, with one main difference. Specifically, in response to the VNOE questions, *what is engineering/ What does an engineer do?* and *How is engineering different from other subjects you are learning?*, the percentage of Treatment students answering uses math/science increased while it decreased for the Comparison group. This is likely due to the immense focus the CREATES Unit (Treatment) places on math and chemistry throughout the 9-11 weeks of implementation (Wilhelm, Wilhelm, Cole, 2019) whereas the Save the Penguins (Schnittka, Bell, & Richards, 2010) curriculum focused more on observing hot and cold objects and then using this to create a protective shelter for an ice penguin.

The source of data collection that revealed the most marked difference between the two groups' understanding was the student interviews. Specifically, the responses to the question *What is engineering/What do you know about engineering?* revealed a stark difference between the Treatment and the Comparison group on both the pre- and post-interviews. For example, pre-instruction, 8 of the 8 interviewed Comparison students answered the question with either an "I don't know," a "nothing," or a question, while 0 of the 8 Treatment students did the same. Post-instruction interviewed Treatment students responded to the question with statements along the lines of engineers design and build, engineers use technology, engineers test water, engineers use math and science, engineers solve problems, and everything is engineering, and everyone is an engineer; the Treatment students never answered the question by stating "I don't know." Half of the post-instruction interviewed Comparison students responded to the question by stating they didn't know. The findings for the interviewed Comparison students are consistent with previous findings that revealed 44% of 1,277 American students (aged 8-17) stated they don't know much about engineering (Katz, 2009). However, the research relayed by Katz (2009) is largely inconsistent with the finding that all of the Treatment students, both pre- and post- instruction, had something valid to say about engineers or engineering. This stark difference between the two interviewed groups was present even before instruction, so it is impossible to attribute this difference to the implemented chemistry-based engineering design unit.

Of the interviewed Comparison students that did not answer “I don’t know” to the interview question *What is engineering/What do you know about engineering?*, answers engineers use science, engineering is mechanical, engineers help make and build, engineers do not experiment, engineers fix cars and put tires together, and engineers use math. Largely, the only difference in understanding in the interview portion between the two student groups is elucidated in interview responses to that one question. The other interview question highlighted here, *is there a difference between engineering (E) and science (S)?*, resulted in similar post-instruction responses from both groups.

It would be simple minded to state this difference in interview responses is due to the instruction received by each group, considering there were marked differences in the Treatment and Comparison group student interviews prior to instruction as well. For example, the pre-instruction Treatment students noted engineers “build things,” use blueprints, use models, use the design process, test for pollution in the air and water, make things, landscape, and design, while, of the 8 pre-instruction Comparison students, five mentioned they didn’t know much or anything about engineering, two noted engineers have something to do with mechanics, and one reported engineers do “everything,” build, use technology, or are car engineers. Additionally, it is important to note that the interviewed students only represent 8 of the students from each group of approximately 100 students (*N*=121 pre-instruction Treatment, N=109 post-instruction Treatment, *N*=97 pre-instruction Comparison, and N=83 post-instruction Comparison), and that the Comparison and Treatment groups as wholes did not differ much in their responses to the VNOE question *What is engineering/What do engineers do?*

With all of this on the table, the answer to the second research question is difficult to confidently supply. However, this specific data set shows the interviewed post-instruction Treatment students have an understanding of engineering and engineers more in line with the definitions used in this paper (i.e. *engineering is the design and improvement of ideas, systems, and products through the use of prior knowledge, mathematics, science, and technology; an engineer problem-solves and innovates to advance the community around them and fulfill a human need)* than do the post-instruction Comparison students in that the Treatment students were all able to supply appropriate information (i.e. design, build, technology, solve problems, math and science, etc.) whereas half of the Comparison students weren't able to provide any information at all to the interview question *What is engineering/What do you know about engineering?* However, as noted before, this likely has nothing to do with the actual Treatment given the already noticeable difference in pre-interviews.

Teacher Understanding of Engineering

To answer the third research question, "How do teacher understandings of engineering and engineers compare to their students?" the teachers were interviewed, and these interviews were compared to the student definitions of engineers and engineering. The teacher interviews demonstrated the teachers largely viewed engineers as problem-solvers. They also viewed them as designers, re-designers, fixers, and assemblers. This view touches on parts of the definition of engineers and engineering used to analyze the data collected in this research, however, the teacher definitions were missing other components of the definitions including innovation and the use of mathematics, science, and technology. Although it may be thought the incomplete student definitions could be attributed to the incomplete teacher definitions (Sadler et al., 2013; Anderson & Mitchner, 1994), it is unlikely the case here since the components of engineering included in the definitions provided by the teachers were not always present in the student definitions and vice versa. This could demonstrate that the students already possessed notions of engineers and engineering prior to entering their 7th grade science class, the teacher definitions from the interviews were not the actual complete understandings held by the teachers, the students are picking up alternative understandings from other classes that may utilize engineering practices (e.g. mathematics class), and/or the students miss the main message of the engineering design process activities by seeing it largely as building rather than the engineering design process.

Recalling that Yaşar et al. (2006) found female teachers rated the importance of design, engineering, and technology higher than did the male teachers, elementary teachers were the least likely to teach design, engineering, and technology, and teachers with moderate experience were the most open to learning more about design, engineering, and technology, it is important to note that three of the teachers in this study were Female (2 Treatment and 1 Comparison) and all mentioned design in their interview definitions of engineering whereas the Male teacher (Comparison teacher 1) did not mention design in his definition, the teachers with the least experience were from the Comparison group (3 and 11 years) as compared to the Treatment teacher experience (16 and 17 years), and all four teachers were middle school science teachers rather than elementary or high school teachers. This ultimately proposes that the Treatment group would be more likely to receive engineering design education (since the teachers were Female and the most experienced), however, this was not reflected in the VNOE results concerning the "have you ever heard of the engineering design process?" question, since both groups were equally unknowing of the engineering design process. However, Yasar et al. (2006) did find that teachers overall were unfamiliar with and lacked confidence in their ability to teach design, engineering, and technology, and they held stereotypes about the skills needed to be an engineer. Since three of the teachers in this mentioned engineering involves design, it is unlikely that that the teachers were unfamiliar with it, especially considering all four of the teachers taught an engineering design-based lesson or unit. However, it may be the case that the teachers - barring the one with a past career as a genetic engineer - lack confidence in their ability, and this affects the translation of information to the students.

Conclusion

With the importance of STEM education to our nation, and the recent implementation of the first set of K-12 education standards to include the subject of engineering (NGSS), it is important to explore the effect of science-based engineering design units/lessons. Through the implementation and completion of student interviews, and student assessments (VNOE & DAET) before and after instruction as well as one-time teacher interviews it was found: (1) students from both groups were more likely to draw engineers performing an appropriate activity; (2) many students viewed engineers as makers/builders/workers (just as they did pre-instruction), however, the percentage of students who listed engineers as inventors, designers, and creators increased; (3) students, from both groups, were less likely to have heard about the engineering design process; (4) students were less likely to consider being an engineer; (5) the interviewed Treatment students were more knowledgeable about engineers than were the interviewed Comparison students, on both the pre- and post-interviews, however, the interviewed Comparison student answers did improve; and (6) in response to the VNOE questions, *What is engineering/ What does an engineer do?* and *How is engineering different from other subjects you are learning?*, the percentage of Treatment students answering uses math/science increased while it decreased for the Comparison group. The findings and conclusions documented in this paper demonstrate student engineering understanding was improved after receiving a science-based engineering design unit/lesson, however, there was still much room for improvement in these understandings. These improvements in engineering education are important to make given the national stress on improving engineering education (Olson & Riordan, 2012; Committee on STEM Education of the National Science and Technology Council, 2018) in order to prepare students to address the prominence of science, engineering, and technology in their everyday life, provide solutions for pressing and future problems, and stop the further decline of the position of the United States in the global economy (National Research Council; 2012).

Limitations and Future Directions

Although this study suggests middle-school science students still possess an inadequate understanding of engineers and engineering, it is important to note this study has its limitations. For example, this study only looks at two schools (one Treatment and one Comparison in Kentucky. Additionally, these schools were not randomly assigned since the Treatment science teachers already had taught the CREATES curriculum in years past and the Comparison school was a new contact. It is also important to note that the teacher lesson plans are limiting in that they only provide a brief description of what was taught in each classroom each day/week, but this fails to detail where the emphasis in any engineering design-based activities was placed (e.g. building versus designing versus fixing versus problem solving). Also, even within the Treatment or Comparison group the emphasis of what engineering is could change based upon the teacher's beliefs of what engineering is. This was not thoroughly investigated in this research. In the future, it would be to capture video footage of both CREATES and the Comparison lessons being taught. This way, the words used to describe engineers and engineering design activities could be investigated, and those popular words could then be compared to the words the students use to describe engineering and engineers to see if the teacher emphasis of what engineering is defined as is a contributor to the students' understanding of engineering. Additionally, further questions could be asked of the interviewed students concerning their exposure to engineering and engineers outside of school such as "does your family ever talk to you about engineering?"; "do you investigate engineering outside of school?"; or "what did you learn about engineering in school prior to this school year?" These questions would help elucidate where students could obtain alternative understandings of engineering in comparison to their current teachers' understandings. In the future, it would also be helpful to allow the teacher understandings of engineering to be triangulated with data just as the student understandings were. Specifically, the teachers could be allowed to fill out the VNOE and the DAET in addition to participating in the interview. It has been thought that if the teachers were given this opportunity initially, then we, most likely, would have seen more complete definitions of engineering from them.

Significance

The data collected and analyzed in this study was consistent with most previous research findings, however, it is one of the first studies to investigate the change in middle level students' engineering understanding after receiving a science-based engineering design unit. For this reason, this study is provocative and calls for further research to corroborate and improve upon it, if improving engineering education is truly important to this nation.

Disclosure Statement

No potential conflict of interest was reported by the author.

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Vita

Emily Driessen was born in Mankato, MN to Jerry and Michelle Driessen. Emily attended North Dakota State University where she earned a B.S. in microbiology and a minor in chemistry. After she graduated, she taught general chemistry laboratories at the University of Minnesota for two years. She then was admitted to the University of Kentucky to the STEM Education Master's program where she worked on her first publication: A Qualitative Study of Baseline Urban and Rural Middle Level Science Teacher and Student Views on Engineers and Engineering.